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PREFACE

This investigation was undertaken to rectify a meteorological deficiency mentioned in a Pennsylvania State College report [5]. This stated deficiency is the lack of information over North America on the diurnal height change in the 500 mb level between standard radiosonde observation times.

This investigation was carried out at the U. S. Naval Postgraduate School, Monterey, California during the period September 1952 - January 1953, in partial fulfillment of the requirement for the degree of Master of Science in Aerology.

The authors wish to acknowledge the assistance and guidance of Associate Professor F.L. Martin and Professor A. B. Mewborn. They also wish to acknowledge the many hours of labor contributed by their wives in transcribing the original data for this investigation.

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TABLE OF SYMBOLS AND ABBREVIATIONS

A_1	Harmonic coefficient of the 24 hour period pressure wave
D_a	Computed monthly average diurnal for a month in which interpolation was used to replace missing observations
$\overline{D}_{a_i}$	Smoothed value of the monthly average diurnal height change for the i^{th} month at a given station
D_A	Computed monthly average diurnal for a month in which all observations are available
h_i	Observed height of the 500 mb surface at 1500 GCT on the i^{th} day of the month
h_i'	Interpolated height of the 500 mb surface for 1500 GCT on the i^{th} day of the month
H_i	Observed height of the 500 mb surface at 0300 GCT on the i^{th} day of the month
H_i'	Interpolated height of the 500 mb surface for 1500 GCT on the i^{th} day of the month
k	Number of breaks in a month's record of observations due to missing observations
m	Population mean or true monthly average diurnal height change
n	Number of days in a given month
$n_{.95}$	Number of individual twelve-hour diurnal height changes needed to establish a 95% confidence limit for the mean
N	Number of years of records needed to establish a 95% confidence level for a monthly average diurnal height change for a given month
P	Probability
S	Standard deviation of the individual twelve-hour diurnal height changes for a given month

t Variable in the students t-distribution

t_p Value of t such that the probability is p that the absolute value of t is greater than t_p

x Number of consecutive missing observations in any given break in the data during a given month

y Number of zero valued twelve-hour diurnal height changes introduced by interpolating for x consecutive missing observations

Y Total number of zero valued twelve-hour diurnal height changes introduced by interpolating for all missing observations during a month's record

$\sum_{i=1}^{n}$ Summation of all observations from $i=1$ to $i=n$.

I. INTRODUCTION

The problem undertaken was to determine a representative monthly mean difference between the observed height of the 500 mb pressure surface at 0300 GCT and 1500 GCT for each radiosonde reporting station within the continental United States and for as many stations as possible in Canada, Alaska, and the bordering seas and oceans.

The results are presented in tabular form in Table 1. which represents the unsmoothed monthly mean diurnal height changes for the entire fourteen months considered and in graphical form in Figures 8 through 19 which show isograms of mean diurnal height change drawn to smoothed values of the monthly mean diurnals for each of the twelve months of the year.

A direct method of computing the monthly mean diurnal height changes from observations recorded for individual stations, as suggested by S. Teweles [11] in his report on the diurnal height changes of the 700 mb surface, was used throughout. Teweles, in his work with the 700 mb surface, abandoned the attempt to use individual station observations in favor of using values for the height of the pressure surface which were interpolated for certain grid points on analyzed contour charts of the 700 mb surface. The formula used in this article to compute the monthly mean diurnal height changes at 500 mb is the same as that used by Teweles for computing the same quantity at 700 mb except for necessary changes made to allow for the effect of missing observations.

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Statistical investigations of the distribution, range, variance and standard deviation of the individual daily twelve-hour height changes at several stations for various months were made. The results of these investigations allow certain conclusions as to the reliability of the results.

The postulated theory of the diurnal pressure wave and its harmonic coefficients is reviewed. The twenty-four hour period pressure wave being due to the twenty-four hour period temperature wave calls for a brief resume of the various parameters which should influence the diurnal temperature variations throughout the atmosphere. Some evidences of the control exerted by local factors, such as type of surface and orography, on diurnal pressure changes are presented.

Cursory comparisons were made of the 500 mb diurnal height change charts with diurnal pressure or height change charts obtained for other levels over the United States, such as the U. S. Weather Bureau [16] surface data, S. Teweles [11] 700 mb data, and O. Wulf, M. Hodge and S. Obloy [19] 10 km data.

The work of H. Riehl [9] and B. Haurwitz [4] at San Juan on the harmonic coefficients of the diurnal pressure wave was investigated to find if the harmonic coefficients determined there were compatible with the findings of this investigation.

Conclusions as to the reliability of the isogram patterns of mean 500 mb diurnal height change are drawn, and estimates of the error introduced by neglecting these 500 mb diurnal height changes are made.

II. DATA

The monthly mean diurnal height changes that are presented in Table 1. were computed from observations taken over a period of fourteen months from September 1948 to October 1949, inclusive. The original goal was to obtain a monthly mean for each of the twelve months based on two consecutive years of observations at each station. However, due to the limited amount of data that was obtainable, in a form which could be handled in anywhere near the time available, the shorter period was utilized.

The source of the observational data used in this work was the Daily Upper Air Bulletin [14]. The data contained in these bulletins are unedited reports taken directly from teletype schedules received in Washington, D. C. In the Daily Upper Air Bulletin, as published by the U. S. Weather Bureau, the heights of all the mandatory levels are tabulated each day for both standard observation times for each station listed in blocks corresponding to the international index numbers. Having the raw data tabulated in this manner facilitated the laborious task of transcribing on to work sheets the approximately 67,000 observations that were used. The form in which the Daily Upper Air Bulletin is currently being published is the reproduction of the actual teletype transmissions. Although a longer record of observations is available in this form, which has been in use since April 1950, the enormous amount of time which would have been required to extract the particular information desired for each station from the total mass of data, prohibited its use.

Observations from seventy-six stations were included in the Daily Upper Air Bulletin regularly enough each month during the period considered to be used in this work. Of these seventy-six stations, forty-seven were located within the continental limits of the United States, twenty-six were located in Canada, one station was in Greenland (Thule) and two were Pacific oceanic stations. Alaskan stations were not used because they were seldom available for more than a few days at a time during most of the months of this period.

III. COMPUTATIONAL TECHNIQUE

1. Basic equations.

The twelve-hour diurnal height change of the 500 mb pressure surface from 0300 GCT to 1500 GCT, hereafter called the diurnal height change, for any given day at a given station, was computed in a manner entirely analogous to that used by Teweles [11] for determining the same quantity at 700 mb. Thus,

$$\frac{h_i - H + h_i - H_{i+1}}{2} = D_i \qquad (1)$$

where,

D_i is defined as the diurnal height change for the day of the month,

h_i is the observed height of the 500 mb pressure surface at 1500 GCT on the i^{th} day of the month, and

H_i is the observed height of the 500 mb pressure surface at 0300 GCT on the i^{th} day of the month.

This method of computing the diurnal height change was selected as being the best estimate of the quantity desired. The averaging process must be depended upon to eliminate the effect of any non-representative twelve-hour height changes that may be introduced by sudden changes in the trend. If the trend is linear for the period from H_i to H_{i+1} the diurnal height change as computed is independent of trend.

The average diurnal height change for a month of n days would be

$$D_A = \frac{1}{n} \sum_{i=1}^{n} D_i \qquad (2)$$

where,

$\sum_{i=1}^{n} D_i$ is the total diurnal height change for the month, and

D_A is the average diurnal height change for the month.

Using the value of D_i from (1), equation (2) becomes

$$D_A = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{h_i - H_i + h_i - H_{i+1}}{2}\right)$$

$$= \frac{1}{n}\sum_{i=1}^{n} h_i - \frac{1}{2n}\sum_{i=1}^{n}\left(H_i + H_{i+1}\right), \qquad (2)$$

whence

$$D_A = \frac{\sum_{i=1}^{n} h_i - \sum_{i=1}^{n} H_i}{n} + \frac{H_1 - H_{n+1}}{2n} \qquad (3)$$

Equation (3) was used to compute the monthly mean diurnal for months in which there were no missing observations. A modification of (3) was necessary, however, in order to compensate for the effect of missing observations.

2. Missing Data.

One important difference between the technique used by Teweles in his work with diurnal height changes at 700 mb and the technique applied here concerns the problem of missing data. By making use of analyzed charts and taking interpolated values of the heights at selected points Teweles avoided this problem. Using the actual observations from the Daily Upper Air Bulletin, however, the problem arose immediately. In 85% of the cases one or more observations were missing from the set of observations from a given station for a given month. Several methods for handling this problem were considered and

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it was decided that linear interpolation between the two observations adjacent to the gap in the data would be used to obtain values for the missing observations. This procedure permitted uniform programming of the operations which followed and allowed the computing of an average diurnal for the entire month instead of several averages for parts of a month which would later have to be combined into an overall average. Interpolation also allowed the use of all the data, whereas breaking the data into segments composed of complete sets of all observations needed for computing a single twelve-hour diurnal height change would require that some reports be discarded. For example, if a single 0300 GCT report were missing and interpolation were not used, breaking the data into two complete sets as described above would discard the 1500 GCT report on either side of the missing observation. Using the interpolation method in the same case would make use of both of these reports.

The linear method of interpolation was selected because it reduced to zero the value of any diurnal height change or part thereof based on interpolated reports. This was compensated by reducing n in equation (3) by the number of zero valued diurnal height changes created by the use of interpolated values during the month.

By far the greatest number of gaps in the data were cases in which a single report was missing. These instances of one missing report occurred at random intervals and with no apparent relationship to the height of the 500 mb surface. Gaps of two missing observations were also quite frequent. For the stations within the United States

there were few gaps of as many as three observations and in only four instances did a break of four consecutive reports occur. The data for non-United States stations were much more irregular with gaps of as many as ten consecutive observations occurring.

The fact that using linearly interpolated height values reduces the diurnals to zero can be readily demonstrated for the case of a single missing observation. If a 1500 GCT observation were missing, h_3 for example, the interpolated value, h_3' , would be

$$h_3' = \frac{H_3 + H_4}{2}$$

The only twelve-hour diurnal height change involving h_3 is D_3 ,

$$D_3 = \frac{2h_3 - H_3 - H_4}{2}$$

and

$$D_3' = \frac{2h_3' - H_3 - H_4}{2} = \frac{2\left(\frac{H_3 + H_4}{2}\right) - H_3 - H_4}{2} = 0 \quad ,$$

where D_3' is the value of the diurnal computed using the interpolated report. If the missing observation were an 0300 GCT report two diurnal height changes, D_2 and D_3 would be effected, but the net result would be the introduction of only one zero valued diurnal with

$$H_3' = \frac{h_2 + h_3}{2}$$

and

$$D_2 + D_3 = \frac{h_2 - H_2 + h_3 - H_4 + h_2 - H_3 + h_3 - H_3}{2}$$

then

$$D_2' + D_3' = \frac{h_2 - H_2 + h_3 - H_4}{2} \quad .$$

The quantity $(D_2' + D_3')$ is equivalent to a diurnal composed of the known parts of D_2 and D_3. As stated above then, a single interpolated observation introduces one zero valued diurnal height change.

For the case of two consecutive missing observations one and one-third zero valued diurnal height changes are introduced. For example, if H_3 and h_3 were the missing observations the two diurnals affected would be D_2 and D_3.

For

$$H_3' = h_2 + 1/3\,(H_4 - h_2) \quad ,$$

$$h_3' = h_2 + 2/3\,(H_4 - h_2)$$

and

$$D_2 = \frac{h_2 - H_2 + h_2 - H_3}{2} \quad ,$$

$$D_3 = \frac{h_3 - H_3 + h_3 - H_4}{2} \quad .$$

Then

$$D_2' = \frac{h_2 - H_2 + h_2 - [h_2 + 1/3(H_4 - h_2)]}{2} \quad ,$$

and

$$D_3' = \frac{h_2 + 2/3\,(H_4 - h_2) - [h_2 + 1/3(H_4 - h_2)] + [h_2 + 2/3\,(H_4 - h_2)] - H_4}{2} = 0$$

Assuming a linear trend existed from 0300 GCT on the second, to 0300 GCT on the fourth, then

$$H_3 = \frac{H_2 + H_4}{2}$$

thus

$$D_2 = \frac{h_2 - H_2 + h_2 - \left(\frac{H_2 + H_4}{2}\right)}{2} = \frac{3/2(h_2 - H_2) + 1/2(h_2 - H_4)}{2}$$

and

$$D_2' = \frac{h_2 - H_2 + 1/3(h_2 - H_4)}{2} = 2/3\, D_2 \quad .$$

As a result of introducing the two consecutive interpolated observations one of the affected diurnal height changes is reduced to zero and the other is reduced by one-third, or one and one-third zero valued diurnal height changes are introduced.

The above proofs can be extended to cover any number of missing observations. If y is the correction factor, expressing the number of zero valued diurnal height changes introduced by x consecutive interpolated observations, it can be shown that

$$y = \frac{x+1}{2}, \quad x \text{ odd}, \tag{4}$$

$$y = \frac{x(x+2)}{2(x+1)}, \quad x \text{ even}. \tag{5}$$

Inasmuch as each interpolation or set of interpolations across a gap in the data can be considered independently of all other interpolations performed during the month, the total correction factor for the month will be the sum of the individual correction factors. If there are k gaps in the data for a given month then

$$Y = \sum_{j=1}^{k} y_j \tag{6}$$

where

Y is the total correction factor for the month,

y_j is the correction factor for the j^{th} gap in the data.

The modified formula for computing an average diurnal height change for a month in which linear interpolation has been used to obtain values for missing observations is

$$D_a = \frac{\sum_{i=1}^{n} h_i - \sum_{i=1}^{n} H_i + \tfrac{1}{2}(H_1 - H_{n+1})}{n - Y}, \tag{7}$$

where D_a is the average diurnal for the month based on $(n-Y)$ individual diurnals. If Y is large D_a will not in general be a good estimate of D_A, the average diurnal height change that would have been obtained had all observations been available. The quantity $(n-Y)$ is then an indication of the reliability of D_a as an estimate of D_A.

Using equation (7) average diurnal height changes were computed for each station for each of the fourteen months considered. These average diurnal height changes are shown in Table 1. together with the quantity $(n-Y)$ that was used in obtaining the D_a that is shown. The entries in Table 1. are in the form $n-Y$, D_a where $n-Y$ is the upper left hand figure and D_a is the lower right hand figure in each entry. The values of these quantities for Atlanta, Georgia (219) for May 1949 are, for example, $n-Y = 28$ and $D_a = 46$

Although the original data were recorded in terms of feet, the value of D_a is recorded to the nearest foot. This is justified because D_a is the average of ten or more observations and therefore contains one more significant decimal place than the individual observations.

IV. STATISTICAL EVALUATION OF RESULTS

1. Variability of individual diurnal height changes.

Before making any statistical evaluation of the results it was necessary to compute the individual diurnals D_i that are averaged in finding the monthly mean diurnal height changes. This was done for twenty-two months of observations from various stations. Only stations for which there were no missing reports during the month being considered were used except in the case of station 219 which had one missing observation from four of the six months used. Histograms were plotted to determine the frequency distribution of the twelve-hour diurnal height changes. The mean, variance, standard deviation, and range were also computed for each month. The values of these quantities are listed in Table 2. Inspection of the twelve-hour diurnal height changes together with their means and variances, shows that much greater twelve-hour diurnal height changes occur during the winter months than during the summer months although the magnitude of the monthly average diurnal height changes vary only slightly. These large height changes which occur during winter are due, in a large part, to the much greater frequency of passages of sharp troughs and strong ridges over the stations during winter than during summer.

2. Confidence limits.

Histograms of the twelve-hour diurnals show that the daily diurnal height changes may be assumed to have a normal distribution. Treating the n diurnals of a given month as a sample of size n from an infinite normal population, composed of all the twelve-hour

diurnal height changes that could be computed for that month for all years. Significance tests based on the students t-distribution, Hoel [5] were made. Using the equation

$$D_A - t_p \frac{s}{\sqrt{n-1}} < m < D_A + t_p \frac{s}{\sqrt{n-1}} \qquad (7)$$

where

D_A is the computed monthly mean diurnal height change,

t_p is the value of t for $n-1$ degrees of freedom such that the probability is p that the absolute value of t is greater than t_p ,

s is the standard deviation of the individual twelve-hour diurnal height changes for the month being considered,

m is the population mean or true monthly mean diurnal height change, and

n is the number of days in the month being considered.

A 95% confidence interval for m was established by setting p equal to 0.05. The values listed in Table 2. under "95% confidence limit" establish the 95% confidence intervals based on the data for the indicated months from the stations listed. The probability is 0.05 that the true monthly average diurnal height change is outside the interval established.

To establish the probability that the monthly mean diurnal computed for any month was within ± 5 feet of the true mean, the following equation taken from 8 was used.

If

$$t_p \frac{s}{\sqrt{n-1}} = 5 \text{ ft.}$$

then

$$t_p = \frac{5\sqrt{n-1}}{s}$$

After finding t_p the value of p was obtained from a table of t values, Hoel [5]. The values listed under "confidence level for $\pm$ 5 feet" are

$$\text{confidence level} = 100(1-p) \quad . \tag{9}$$

These values express a confidence level for the statement

$$D_A - 5\,\text{ft.} < m < D_A + 5\,\text{ft.} \quad . \tag{10}$$

To attain an estimate of how many years of observations would be required to establish a confidence level of 95% for (10) the following equation was used:

$$t_{0.05} \frac{S}{\sqrt{n_{.95}-1}} = 5\,\text{ft.}$$

or

$$\frac{t_{0.05}}{5} S = \sqrt{n_{.95}-1} \quad .$$

For an infinite number of degrees of freedom

$$t_{0.05} = 1.645$$

and it follows that

$$\frac{(.329S)^2+1}{30} = \frac{n_{.95}}{30} = N \quad , \tag{11}$$

where

$n_{.95}$ is the number of individual twelve-hour diurnal height changes needed to establish a 95% confidence level for (10) with the existing standard deviation,

S is the standard deviation of the twelve-hour diurnal height changes for the month being considered,

N is the number of years of data needed for the given station and month to establish 95% confidence level for (10).

The results obtained using (11) are listed in Table 2. under N.

Results of the t-test indicate that the monthly average diurnal height changes obtained in this investigation are of the proper order of magnitude. The tests show that if monthly averages were obtained for each of 100 years for a given month at an average station, 95 of these monthly averages could be expected to fall in the interval $D_A \pm 25$ feet where D_A is the monthly average diurnal computed for the given month and station in this investigation.

3. Smoothing.

Because of the variability of the individual diurnals and the apparently random month to month irregularities in the average diurnal height changes a smoothing operation was employed before the monthly average diurnals were plotted and isolines drawn. A three month weighted running mean was used. Inasmuch as the number of diurnals included in D_a for different months was not constant a weighting factor was employed to adjust for the difference in precision of D_a as an estimate of the true mean diurnal height change, for different sample sizes. The relative precision of two sample means for estimating the population mean is the ratio of the square roots of the number in each sample. For this reason the quantity $\sqrt{n-Y}$ was

used as a weighting factor for each monthly average. The values plotted on the charts in Figures 8-19 were obtained by use of the formula

$$\overline{D_{a_i}} = \frac{\sqrt{n_{i-1}-Y_{i-1}}\, D_{a_{i-1}} + 2\sqrt{n_i-Y_i}\, D_{a_i} + \sqrt{n_{i+1}-Y_{i+1}}\, D_{a_{i+1}}}{\sqrt{n_{i-1}-Y_{i-1}} + 2\sqrt{n_i-Y_i} + \sqrt{n_{i+1}-Y_{i+1}}} \tag{12}$$

where

$\overline{D_{a_i}}$ is the smoothed value of the monthly average diurnal height change for the i^{th} month at a given station,

n_i-Y_i is the number of diurnals used in computing D_{a_i} and

D_{a_i} is the monthly average diurnal height change for the i^{th} month at the given station.

The quantity $(\sqrt{n_{i-1}-Y_{i-1}} + 2\sqrt{n_i-Y_i} + \sqrt{n_{i+1}-Y_{i+1}})$ was plotted alongside each station, Figures 8-19 together with D_a as a measure of the reliability of $\overline{D_a}$.

The above method of smoothing preserved the positions of the major maximum and minimum average diurnals but made the plot of monthly mean diurnals look more reasonable. Examples of the effect of the smoothing process on the plot of the monthly values is shown by Figures 1-7.

V. THEORIES OF THE DIURNAL PRESSURE VARIATION

The basic causes of the atmospheric diurnal pressure variation are absorption of solar radiation, infra-red radiation and absorption, and solar tidal effects. This diurnal pressure variation, which at the surface normally has two maxima and two minima each twenty-four hours, can be broken down by harmonic analysis into a fundamental twenty-four hour period which is called the diurnal pressure wave (contrasted to the diurnal pressure variation) and harmonics of this period. Normally the second harmonic (twelve-hour period), which is called the semi-diurnal wave, is of amplitude comparable to the fundamental. An appreciable third harmonic (eight-hour period) and a minor fourth harmonic (six-hour period) have been found in the analyses of certain station mean pressure records as reported by Albright [1, pp 64-70].

The semi-diurnal (twelve-hour period) pressure wave has been subjected to a great deal more investigation than has the diurnal (twenty-four hour period) pressure wave because it is believed to be the basic cause of the daily terrestrial magnetic variations. This semi-diurnal pressure wave is attributed to solar tidal action and the magnifying effect of a natural periodicity of the atmosphere of twelve hours. This wave has been found to decrease with altitude at the same rate as the pressure decreases with altitude by Hann [3, p 207] , and at a less rapid rate by Riehl [9] and Haurwitz [4] .

The diurnal pressure wave (twenty-four hour period) is attributed by Humphreys [6, pp 243-244] to the diurnal heating and cooling of the total atmosphere. On the side of the earth subject to insolation the

atmosphere will be expanded and on the opposite side, contracted. At higher altitudes on the heated side the isobaric surfaces will be raised and the pressure at a fixed upper elevation will rise. At night the reverse is true, the isobaric surfaces lowering due to the air column contraction, and the pressure at a fixed upper elevation falling. These variations should be greatest near the times the air column is the warmest and coldest. Accompanying both of these variations, vertical motions are causing moderating adiabatic temperature changes at the upper levels.

At the surface the pressure changes can be expected to be reversed; i.e., a fall during the day and a rise at night. This is due to the pressure gradient aloft that is established between the warm side and the cold side of the earth and the resultant mass transport from the warm side to the cold side. The rise in pressure at the surface on the cold side and the fall in pressure at the surface on the warm side in turn result in a moderating mass transport from the cold side to the warm side at low levels. Thus a vertical circulation is set up, much as in the case of the sea-land breeze cell. By this theory there will be a level where the horizontal pressure gradient due to the diurnal pressure wave is zero.

No theory for the origin of the eight-hour and six-hour diurnal pressure waves has been noted but they are probably the result of similar periodicities in the temperature cycle of the atmosphere.

VI. FACTORS INFLUENCING THE DIURNAL PRESSURE WAVE

Assuming that the diurnal pressure wave is brought about by the diurnal temperature wave throughout the entire atmospheric column, there are several parameters which must exert an influence on the diurnal pressure wave at the surface or at any particular elevation.

Latitude and season are the most obvious factors since they determine the amount of insolation on the top of the atmosphere.

The distributions of temperature, water vapor, ozone, pressure, and carbon dioxide with height are fundamental to the problem since they determine the amount of solar absorption and long wave absorption and radiation at any particular height with given amounts of incident radiation.

In addition to the controls exerted by the above parameters on the atmospheric temperature and pressure differences there are those arising from the type of earth surface and orographic features. Evidences of these controls in establishing local diurnal pressure differences and broadscale diurnal pressure differences are apparent in the investigations discussed below. While these examples refer to local influences on the diurnal pressure variation and the resulting circulation patterns, it is logical to assume that these factors also affect the diurnal pressure wave, since the diurnal temperature wave should be affected in each case.

(a) Land-sea breeze

Van Bemmelen [17], in a study on Batavia, Java found that the low level sea breeze exists during the time the pressure over the sea exceeds that over the land (1100 to 1930 local time). This sea breeze existed up

to 875 mb and an opposite land breeze existed from there up to about 650 mb. The land breeze was about one-half the intensity of the sea breeze but was extended through about twice the depth. On the basis of this it would appear likely that local or small scale influences on the diurnal horizontal pressure gradients would become zero at about 875 mb and would be in reverse phase from there up to 650 mb. Above that height local influences should have no effect and the observed diurnal pressure wave would be due to large scale action. This postulates no orographic barriers to prevent the vertical circulation cell from being established.

(b) Continent - ocean and mountain - plains winds

R. Wexler [18] quotes examples of broadscale diurnal continent-ocean winds and mountain-plains winds due to the same phenomena as the land-sea breeze. A continent-ocean wind has been found to exist up to 1300 meters over Europe with zero horizontal pressure gradient at 1300 meters, reverse winds from 1300 to 4500 meters, and no observable effect above approximately 4500 meters. A continent-ocean wind exists in the United States with zero horizontal pressure gradient at 3100 meters, the height to which the reverse pressure gradient exists being unknown. A United States mountain-plains wind exists with zero pressure gradient at 2500 meters m.s.l. and with the top of the reverse circulation being unknown. These phenomena would indicate that the relatively broadscale diurnal pressure wave influences could be effective up to or above 500 mb.

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[illegible]

[illegible]

(c) Local differences in the diurnal pressure variation

An Army Air Force report [13, pp 2-4] gives the normal surface midsummer diurnal pressure variation for exposed coastal stations, coastal valley stations, and interior valley stations along the U. S. Pacific Coast. It also gives the diurnal differences between these three curves. The difference curve between the interior valley and coastal stations has an amplitude of almost 2 mb and has a maximum value at 0800 local time and a minimum at 1800 local time. This difference curve is for areas only about 100 miles apart and is presumably due to the differences in the diurnal temperature range of the lower atmosphere at the two locations and the presence of the coastal mountain ranges. Over the dry cloudless interior valleys the ground receives a large amount of solar radiation and the surface temperatures reach high values during the day. This heat is carried into the lower few thousand feet of the atmosphere by turbulent transport. At night the surface radiation is very large, since the lower atmosphere is relatively dry, and the surface temperature drops, together with the temperature in the very low layer of the atmosphere. At the coastal stations, however, the low level diurnal temperature range is small due to the stabilizing influence of relatively constant water temperature, the layer of moist air and frequent cloud cover. The coastal mountain ranges reduce the intensity of the vertical circulation cells which would normally be established by these surface pressure differences and as a result the moderating effects of mass transport on the local surface pressure differences are considerably less than might be expected.

Cloud amounts, densities, thicknesses and heights are important considerations in the problem. J. London [7] calculated the radiational temperature change in the atmosphere in March from the equator to 90° North using average conditions for each latitude, first assuming clear skies, and then using the average cloud amount, thickness, etc. for each latitude. His data showed that the cloudy skies served to increase both the infra-red cooling and the solar heating of the layer at about 3 or 4 km. over that found for clear skies. These cloudy sky conditions should increase the diurnal temperature variations at that level and bring about a modifying influence on the diurnal pressure wave.

J. Spar [10] has made an analysis of the surface diurnal (twenty-four hour period) pressure wave amplitude at New York City for a limited number of days broken down into the categories shown in Table 3., where A_1 is the coefficient of the fundamental twenty-four hour period pressure wave.

		No. of days	A_1 (mb)	Time of maximum
Summer	cloudy	24	.21	0555 local
	clear	27	.71	0705 local
Winter	cloudy	43	.57	0900 local
	clear	27	.80	0425 local

The characteristics of the 24 hour surface pressure wave at New York City

Table 3.

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	

[illegible]

This data shows that the surface diurnal pressure wave is greater on clear days than on cloudy and that the time of the maximum is earlier on cloudy days than on clear days in the summer but is later on cloudy days than on clear days in the winter.

Any consistent diurnal variation in atmospheric adiabatic motions or in the amount of water vapor condensed out at a given location will result in diurnal temperature changes.

In addition to all the preceding parameters influencing the diurnal (twenty-four hour period) temperature and pressure waves there are probably others, including a small solar tidal influence.

VII. RESULTS AND DISCUSSION

1. Presentation of results.

Incorporated in the values of the 500 mb diurnal height changes as determined herein are two extraneous factors that must be considered.

The first of these is the radiational effect on the temperature sensing element during daylight hours. Using temperature corrections supplied by the U. S. Weather Bureau for the instruments used, H. Riehl [9] found that the total diurnal pressure range at 500 mb was reduced to 50% of the value obtained without the temperature correction. Since the maximum pressure at 500 mb at San Juan occurred near local noon this radiational error should be progressively less in going from east to west across the United States where the standard observation time (1500 GCT) corresponds to 1000 local time on the east coast and 0700 local time on the west coast. Also, the effect should decrease with increasing latitude northward of San Juan. In any investigation of causative factors in the diurnal pressure wave this type of error would have to be considered. However, for synoptic utilization of the normal diurnal height or pressure changes at any particular height, it should not be too important, provided instruments with approximately the same radiational error characteristics are employed in the future.

The second extraneous factor results from the use of the phrase diurnal wave to signify the quantity under study here. In its usual context it represents the sinusoidal variation of a twenty-four hour period. However, when twelve hour differences are taken on a basic

twenty-four hour period, non-sinusoidal curve, such as the total diurnal pressure variation, not only a component of the fundamental twenty-four hour period is obtained, but also a component of all odd harmonics of this twenty-four hour period. As a result of this, the term diurnal height change, when applied to the results of this study, incorporates a contribution from the twenty-four hour period pressure or height wave and also from any eight hour period, 4.8 hour period, etc., pressure or height wave that may exist at the particular station.

The smoothed values of monthly mean 500 mb diurnal height change (1500 GCT - 0300 GCT) as obtained by the methods described previously, were plotted on a standard map projection and isograms for each ten feet were drawn. By virtue of the weighted running mean technique used in this study, average monthly maps were obtained for twelve months (October 1948 through September 1949), Figures 8-19, from the original fourteen months (September 1948 through October 1949) data. Partial data was obtained for Bermuda and the two Pacific weather ship stations, No. 101 and No. 102, but due to the distance between these points and other data points, no attempt was made to draw isograms for them. The isogram analysis over the continental United States is fairly well established by the density of reports but over the Canadian area, where reports are widely scattered, the analysis is somewhat arbitrary. Where the pattern was arbitrary, that one was adopted which most nearly retained the same general configuration throughout the year. The month-to-month variations of the patterns are, of course, not large since, for adjacent months, part of the same data is incorporated by the weighted running mean technique used. A more critical test for the seasonal

variation in patterns is obtained by comparison of maps three months apart since these would have no common data. This type of comparison shows that the basic pattern along the coastal areas is similar throughout the whole year but that the intensities of the positive and negative areas may change considerably. Over the central part of the continent the variations in patterns and intensities are both quite large, the only consistent features being the large positive area throughout the year in central Canada, and the area near zero over the northern Great Lakes region.

The annual mean 500 mb diurnal height changes (October 1948 through September 1949) were also plotted and isograms drawn, Figure 20. This map eliminates some of the irregular features of the monthly mean maps and serves to high light the more or less permanent features of the pattern. The irregular features eliminated represent the seasonal variations as determined by the data and techniques used.

For seven United States stations both the unsmoothed and smoothed monthly mean 500 mb diurnal height changes (1500 GCT - 0300 GCT) were plotted for the year, Figures 1-7.

2. Comparison with investigations at other levels.

A cursory comparison of the 500 mb diurnal height change maps was made with diurnal pressure or height change charts obtained for other levels over the United States. Any marked similarity cannot be expected, however, since the surface data represents the normal values obtained from a ten year period (1931 through 1940), the 700 mb data

represents the values obtained from a two year period (January 1947 through December 1948), and the 10 km data presents the values obtained from a five month period (February 1942 through June 1942) which were for slightly different sounding times (1600 GCT - 0400 GCT).

The surface data used was based on a comprehensive work by the U. S. Weather Bureau [16] in which three, six, and twelve hour normal surface pressure changes are given for 100 United States stations, based on 10 years data. Although the twelve hour changes given there do not correspond to the twelve hour interval with which this investigation is concerned (1500 GCT - 0300 GCT), it was possible to obtain that twelve hour difference by using two of the three hour change values and one of the twelve hour change values thus:

$$(1500 - 0300) = (1800 - 0600) - (1800 - 1500) + (0600 - 0300)$$

For comparison purposes the ten year normal surface diurnal pressure changes were found in the manner described above for the months of January, April, July and October, these months being taken as representative of the four seasons. These values were plotted in units of 1/10 mb on maps, Figures 21-24. Isograms were then drawn in terms of equivalent height change of the pressure surface at the ground, the conversion used being .375 mb equals 10 feet. This is arbitrary and is inaccurate in that it does not take into account the differences in mean monthly surface pressure that exist between stations. The greatest inaccuracies will, of course, exist for the mountain stations. However, for the purposes for which the data is used herein, these inaccuracies are not important.

The first feature which appears on examination of the four monthly mean surface diurnal height change (1500 GCT - 0300 GCT) maps is the predominance of positive values over most of the United States. By contrast, at the 500 mb level, relatively large areas of negative diurnal height changes are in evidence. This is also shown by examination of Figures 1-7 where the simultaneous values of surface and 500 mb diurnal height changes are exhibited.

The order of magnitude of the height changes at the two levels is the same. If expressed in equivalent pressure change, however, the changes at 500 mb are considerably less than at the surface. There are some relations that persist between the two levels throughout the whole year. Over the Florida peninsula small positive values occur at the surface and large positive values occur at 500 mb. East of Maine and over southern Nova Scotia values near zero occur at the surface and large positive values occur at 500 mb. Over the northern part of the Great Lakes region and on the Oregon and Washington coast, values near zero occurred at the surface and at 500 mb.

In view of the basically irregular pattern of the monthly mean surface diurnal height change maps, it was decided not to smooth geographically the values plotted on the 500 mb diurnal height change charts as S. Teweles [11] did at 700 mb. Any such geographic smoothing would postulate that local small scale influences are not significant in the 500 mb diurnal height change values and such has not been confirmed by this study.

Figures 1-7 show that at Atlanta, Phoenix, Rapid City, and for part of the year at Chicago there is a marked similarity between the variation throughout the year of the normal monthly mean surface diurnal height changes and the smoothed monthly mean 500 mb diurnal height changes. The magnitude of the height changes at these stations is generally less at 500 mb than at the surface and for parts of the year actually represents a change in sign at the two levels.

The 700 mb data comparison was based on the study by S. Teweles [11] who has determined a set of tentative normal monthly mean 700 mb diurnal height changes (1500 GCT - 0300 GCT) based on two years data. His method of determination of the monthly mean diurnals at grid points is described in Chapter III. He then compared the plot of the diurnal variation throughout the year at each grid point with that at surrounding grid points and made whatever smoothing adjustments were necessary to make the curves compatible with each other, in a given area, and with a uniform cyclic change throughout the year. As a result of the smoothing process used, the 700 mb data has a relatively smooth pattern of isograms for the monthly means over the United States. The principal difference between the 500 mb and the 700 mb monthly mean maps is that smoothness of the 700 mb data contrasted with the irregular pattern at 500 mb, particularly inland from the coast. The points of similarity are that the order of magnitude of the changes is the same at the two levels, large positive values persist at both levels over Maine and Florida, and moderate negative values persist at both levels over Vancouver Island.

A 10 km data comparison was based on work by O. Wulf, M. Hodge, and S. Obloy [19] in which they have considered the diurnal changes in temperature and pressure for United States stations. They have plotted unsmoothed monthly mean 10 km (260 mb) diurnal pressure changes (1600 GCT - 0400 GCT) for February 1942 through June 1942 for thirty United States stations. This comparison shows the principal difference to be the order of magnitude of the diurnals at the two levels. In terms of pressure, the values at 10 km are three to six times as large as those at 500 mb. The patterns are equally irregular inland from the coastline but large positive values persist at both levels over Maine and Florida, and values near zero persist at both levels over the northwest corner of the United States.

3. Correlation with physical parameters.

Using the synchronous data from the Monthly Weather Review [15], a check was made as to any similarity in patterns between the 500 mb diurnal height change maps and the monthly mean maps of pressure and temperature at standard levels, percent clear sky, and departure of mean temperature from normal. There were agreements in patterns in areas and for certain seasons but these were not consistent. Considering the average monthly solar radiation received at the surface at Washington, D. C., Columbia, Missouri, and Nashville, Tennessee, it appears from cursory inspection that there may be a negative correlation between the amount of radiation received at the surface and the 500 mb diurnal height change. This matter was not verified statistically.

4. Comparison with harmonic analysis obtained by other investigations.

H. Riehl [9] and B. Haurwitz [4] have, on the basis of soundings every three hours at San Juan for the period of October and November 1944, determined the harmonic coefficients of the diurnal and semi-diurnal pressure waves from the surface up to 16,000 meters. They obtained a maximum diurnal (twenty-four hour period) range of about 122 feet at 6100 meters. The maximum in this twenty-four hour period wave occurred at 1227 local time (1657 GCT). The maximum in the twenty-four hour period temperature wave at 6100 meters occurred at 1218 local time. If this phase relation between the twenty-four hour period pressure wave at 500 mb and the sun holds generally, then for the standard observation times (1500 GCT - 0300 GCT) a maximum positive diurnal height change would occur at 500 mb on longitude 37° West, a zero value at 127° West, and a maximum negative value at 143° East. From the maps of this investigation, which covers only approximately 50° longitude, any such uniform longitudinal gradation is not apparent.

Using Riehl's diurnal variation curve of the pressure over San Juan at 6100 meters the actual diurnal height change for the standard observation times (1500 GCT - 0300 GCT) was found to be about +120 feet. This is considerably greater than the largest monthly mean value obtained in the United States in the current study, which was +56 feet at Miami in October.

W. Humphreys [6] quotes the value of maximum range for a third harmonic wave (eight hour period) at the surface of .30 mm with maximum at 30° North and 30° South. This wave has opposite phase in

[illegible]

[illegible]

the two hemispheres, has opposite phase in winter and summer, is zero at the Equator, and in the northern Hemisphere winter has its maxima at 0200, 1000, and 1800 local time. No studies have been noted on the existence of the third harmonic above the surface. If it does exist generally, its additive and subtractive effects on the observed 1500 GCT - 0300 GCT height or pressure change would be a maximum at longitude intervals of 60°. Any such general 120° longitude wave-length pattern, superimposed on a 360° longitude wave-length pattern due to the twenty-four hour period wave, is not apparent from this study.

5. Synoptic considerations.

In the analysis of the raw data of this study it was quite apparent that the passage of a very sharp, deep trough, or a predominance of trough lines over ridge lines, at a particular observation time throughout a month would give a positive or negative bias to the mean diurnal for that month. The bias was positive if the observation time was 0300 GCT and was negative if the observation time was 1500 GCT. The same type of consideration applied to a sharp ridge line, or a predominance of ridge lines over trough lines, at a particular observation time. In this case the bias values are of opposite signs for the identical observation times.

This bias, of course, arises from the technique used in determining the mean diurnal height change. However, with only two soundings per day, there is no other practicable method where large masses of data are to be processed. The only effective way of removing this bias is to have enough years of data for the given month so that such random biasing effects are nullified.

These biasing effects are the primary cause of the marked differences that occur at some stations between the unsmoothed mean diurnals for successive months. This applies to a lesser degree to the differences between smoothed values. The map of mean diurnal height changes for the whole year, Figure 20, should have effectively removed any such biasing effect due to the number of observations comprising it.

Granting that the individual monthly mean diurnal maps have considerable error in certain areas due to the above considerations, it is still apparent from the mean map for the year that there are areas in North America where there is a marked gradient in the diurnal height change values. It is also apparent that local geographic influences such as type of surface, orography, etc., are of primary importance in the 500 mb diurnal height change patterns over North Americal.

With the type of data and the unsmoothed form of the diurnal height change patterns obtained in the current study it is impossible to ascribe the pattern to a certain twenty-four hour wave component and/or a certain eight hour wave component at a given station, since both the amplitude and phase of both waves are unknown. The solution to this problem must await the availability of data similar to that of Riehl's at San Juan for many more stations.

If the findings of this study can be assumed as being representative of the general pattern and order of magnitude of the normal monthly mean 500 mb diurnal height change, the question then arises as to the effect of this diurnal on normal synoptic upper air analysis routine.

In determining the twelve hour height tendency at a given point the first twelve hour height tendency will include an error equal to, and of the same sign as the diurnal height change for that point for the same twelve hour period. For the subsequent twelve hour height tendency at that point the error will be of the opposite sign but of the same numerical value. Thus the net error in two consecutive twelve hour tendencies at a given point will be twice the magnitude of the diurnal height change.

It is apparent from the mean 500 mb diurnal height change map for the year, Figure 20, that the areas where this error will generally be the greatest are (1) in the Goose Bay, Labrador area; (2) in the Sable Island area; (3) just north of Vancouver Island, and (4) over the Florida peninsula. On the basis of the mean map for the year the average resultant error in two consecutive twelve hour height tendencies in these areas will be about 100 feet. However, if the values near Sable Island and Goose Bay shown in Figure 17 are actually representative of normal summer values, the resultant error in these areas will be about 190 feet. The fact that these errors will be of opposite signs at these two locations will cause, on successive twelve hour height tendency maps, an apparent north-south oscillation of height tendency centers passing through this area.

An analogous statement may be made regarding errors in thickness tendency values deduced from successive twelve hour thickness tendency maps. However, in this case it is necessary to consider the difference between the diurnal height changes at the upper and lower boundaries of the layer.

If the magnitude of this thickness tendency error in the layer from 1000 mb to 500 mb is determined from the mean 500 mb diurnal height change map for the year, Figure 20, and the U. S. Weather Bureau monthly mean surface diurnal height change maps for the United States only, Figures 21-24, it is found to be a maximum in July. It is approximately 100 feet in an area extending from east central California through southern Arizona and New Mexico and into southwest Texas. The boundary level contributing most of this error is the surface since it has very high diurnal height changes in this same area in July.

No conclusions can be drawn from this study as to the error in a given station 500 mb height since the diurnal pressure variation at this level is not known.

An analogous statement may be made regarding the error in a given layer thickness since, to determine this error, the diurnal pressure variation at both boundaries must be known.

VIII. CONCLUSIONS AND RECOMMENDATIONS

To establish the causative parameters in the 500 mb diurnal height changes it would be necessary to carry out the type of study that H. Riehl [9] performed at San Juan for several different stations and for a longer period of time than used there. Multiple correlation studies would then have to be made on the correlation between possible causative parameters and the 500 mb diurnal height changes.

The 500 mb diurnal height changes in particular areas of North America can introduce significant errors in the twelve hour height tendency maps and in the twelve hour thickness tendency.

Statistical investigation of the twelve hour diurnal height changes show that the confidence level for believing that the values of the monthly average diurnal height changes, presented in Table 1,are within the limits of accuracy of the height observations is only about 70%. This level of belief is not high enough to permit the direct use of this table as a source of correction factors to be used in the daily analysis of 500 mb. charts. The charts, Figures 8-19, are more reliable due to the greater number of observations included in each plotted value by virtue of the smoothing operation employed, but still do not represent an accuracy that would permit a mechanical application of the exhibited information.

In order to obtain a monthly average diurnal height change with an accuracy of ± 5 feet it would be necessary to process data covering an average period of twelve years in the case of summer months and an average period of forty-five years for winter months. It is suspected that

additional significance tests would show that all the summer months could be assumed to come from the same parent population and therefore could be treated as one large sample, in which case a record of only about two years observations would be needed to obtain a good estimate of the true monthly average diurnal height change. Similar tests may also show that the winter months are essentially homogeneous in which case a record for about eight years of observations would give the desired accuracy.

In view of the above considerations it is the conclusion of the authors that the mean annual 500 mb diurnal height change map, Figure 20, could be utilized to advantage by upper air analysis activities until such time as more extensive investigations have produced mean monthly diurnal height change maps of the desired accuracy. It is therefore recommended that the mean annual 500 mb diurnal height change map be disseminated to Naval activities and other interested agencies carrying on upper air analysis programs over North America.

It is further recommended that the problem of establishing normal seasonal or monthly 700 mb, 500 mb, 300 mb, and 200 mb diurnal height changes for all radiosonde reporting stations in North America, the Pacific, and the Atlantic be continued.

	202	20[illegible]	211	219	231	240	250	253	265	270	27[illegible]
	21	27	27	29	21	28	28	27	26	25	25
Sept 48	59	35	51	33	16	32	04	1[illegible]	34	-02	16
	23	26	28	30	20	29	29	29	27	26	23
Oct 48	62	25	44	26	36	25	35	35	22	00	-12
	21	29	28	26	18	26	25	27	28	25	27
Nov 48	42	52	53	29	23	33	12	08	11	54	-20
	28	28	30	30	29	26	29	29	24	28	27
Dec 48	46	38	42	02	34	30	16	14	-15	10	-18
	27	28	29	28	24	27	29	24	16	26	28
Jan 49	35	35	65	06	18	04	09	-25	-20	34	-03
	27	24	26	27	21	26	24	24	26	23	23
Feb 49	28	03	48	36	16	18	-05	06	-12	-36	11
	27	30	31	30	30	30	28	29	27	31	30
Mar 49	31	-13	38	-12	22	07	12	-07	01	31	-04
	22	29	29	29	26	27	27	25	29	29	29
April 49	13	-06	35	21	15	37	28	13	01	11	09
	30	29	31	28	30	29	29	26	31	31	31
May 49	31	20	25	46	33	12	44	17	17	02	-06
	28	28	29	30	29	30	28	28	30	30	29
June 49	26	15	31	22	17	05	27	08	33	14	24
	29	28	30	30	27	31	28	30	30	29	31
July 49	49	20	35	27	21	09	28	11	30	-01	15
	30	30	27	31	26	28	30	29	30	29	29
Aug 49	23	14	24	-02	23	25	55	10	07	-05	12
	29	28	30	30	25	25	28	28	28	28	29
Sept 49	47	16	45	27	08	19	56	-04	04	08	-19
	27	29	27	30	25	28	29	28	29	28	30
Oct 49	37	23	33	19	17	20	45	-26	07	00	-29

Table of monthly mean 500 mb
diurnal height changes

Table 1.

Table 1. (Continued)

	304	317	327	340	353	365	376	394	405	445	451
Sept 48	24 27	29 34	27 36	24 12	29 14	22 10	25 00	23 -16	27 25	30 16	29 09
Oct 48	27 31	30 37	25 45	27 -02	29 08	30 -12	24 -12	25 -37	28 12	30 28	30 -03
Nov 48	28 28	27 12	23 37	27 -23	25 21	30 14	23 16	26 -11	29 39	29 21	25 14
Dec 48	28 62	30 20	29 01	30 44	30 -03	27 -05	24 00	18 -14	29 45	28 42	31 22
Jan 49	26 50	27 40	27 20	28 08	25 -06	28 03	28 -13	28 -22	27 29	28 28	28 06
Feb 49	23 22	24 16	26 13	26 -20	25 38	25 02	25 -36	26 -22	25 12	24 30	26 -9
Mar 49	30 36	30 06	31 07	31 33	31 -13	30 16	31 -17	31 -23	30 14	30 28	29 13
April 49	26 13	29 06	29 15	29 37	29 -8	27 -19	26 04	28 -09	28 -16	28 -01	29 -06
May 49	28 25	29 30	30 04	19 -11	29 -27	31 -06	31 -04	31 -01	26 -06	30 03	30 02
June 49	28 22	30 30	30 10	30 07	29 11	30 -11	29 -09	30 -17	30 02	30 09	29 05
July 49	30 12	31 21	27 11	31 32	31 05	30 16	30 20	30 -13	30 16	30 06	30 01
Aug 49	28 29	29 12	30 04	31 07	31 -03	30 -06	30 -27	29 03	27 18	31 05	31 06
Sept 49	27 41	30 22	28 08	26 04	30 13	30 -02	29 -09	27 09	26 10	29 11	28 -01
Oct 49	30 31	29 23	29 13	27 09	28 03	30 20	29 -25	30 -15	30 18	28 00	29 06

Table 1. (Continued)

	476	486	493	506	520	528	534	536	553	562	576
	29	24	27	23	29	28	27	27	29	29	29
Sept 48	05	15	04	45	20	27	55	07	16	20	-04
	28	26	25	14	24	29	29	31	29	27	29
Oct 48	14	-42	-06	41	53	59	03	43	-04	16	03
	27	24	27	21	24	29	28	28	29	25	29
Nov 48	14	22	-09	-11	34	19	32	31	-10	12	12
	28	28	21	25	26	25	29	26	29	27	27
Dec 48	-27	-26	10	34	-19	7	18	30	76	23	-53
	27	25	25	28	27	25	27	27	27	26	27
Jan 49	05	-48	13	09	04	36	06	-18	-09	06	-12
	24	26	25	26	27	23	27	26	26	25	24
Feb 49	17	00	-38	39	09	-25	45	21	2	-43	-23
	30	29	31	26	30	29	31	30	29	30	29
Mar 49	-46	-32	00	30	38	39	09	·10	33	-42	-18
	29	28	29	27	29	29	27	29	29	29	29
April 49	-08	-03	24	09	-30	19	09	-38	19	-5	02
	31	31	30	28	31	30	31	30	31	31	31
May 49	-34	-12	-02	35	24	15	-07	21	13	07	-23
	30	30	29	27	30	25	25	27	29	29	30
June 49	-24	-28	-15	36	04	-19	00	22	17	25	-19
	31	30	31	25	22	29	31	27	31	28	30
July 49	13	-19	-28	33	25	24	25	16	07	14	19
	31	30	31	28	25	29	31	28	31	29	31
Aug 49	-05	-17	-24	46	15	34	11	25	13	13	-08
	27	30	29	27	29	24	29	22	30	30	29
Sept 49	-10	-09	-20	32	17	19	30	69	04	30	32
	30	29	28	28	26	27	30	25	29	30	30
Oct 49	11	-26	-14	37	18	22	17	30	23	-26	-21

Table 1. (Continued)

	597	600	606	655	662	681	712	734	747	764
Sept 48	26 -15		28 49	2[illegible] 03	27 -21	28 -39	24 07	28 46	27 15	23 05
Oct 48	25 17	10 62	23 26	27 12	28 -08	25 -09	29 -07	29 -01	25 12	23 56
Nov 48	24 -27	21 93	27 67	25 08	28 -09	29 -11	28 36	26 -44	26 12	28 12
Dec 48	23 13	04 35	29 43	23 18	28 -16	30 -26	31 17	28 -09	28 34	24 56
Jan 49	30 06		23 40	27 11	16 -13	22 -02	31 37	25 33	26 -11	27 28
Feb 49	23 25		25 59	24 02	26 -11	23 -04	26 32	22 03	27 -29	23 23
Mar 49	30 06		29 26	29 -06	31 -26	29 -30	29 46	31 33	31 -23	30 -22
April 49	29 -01		29 58	29 14	28 09	29 -25	27 15	29 02	28 02	28 -21
May 49	31 -20		27 09	30 12	29 -13	31 -12	31 27	31 17	29 -18	31 00
June 49	30 -05	26 81	28 31	30 14	29 06	30 -33	28 37	28 -24	26 10	29 -24
July 49	25 -18	18 99	31 08	27 -22	25 21	30 -31	25 38	30 19	31 -44	31 05
Aug 49	31 -14	23 87	28 16	31 -15	30 -08	31 -15	30 -12	31 22	29 -04	29 -01
Sept 49	27 -17	21 39	27 28	29 -03	28 01	30 -07	22 29	29 -11	28 -09	30 -21
Oct 49	30 -01		30 46	30 04	28 -30	30 -19	30 32	28 -20	30 12	30 -14

Table 1. (Continued)

	76[illegible]	775	7[illegible]5	79[illegible]	202	[illegible]15	[illegible]16	[illegible]26	[illegible]36	[illegible]67
Sept 4[illegible]	29 -25	2[illegible] -19	24 -11	27 -20	21 0	12 -18	9 -4[illegible]			22 10
Oct 48	26 13	26 -15	26 -29	27 -23	1[illegible] -23	20 31	20 -40	[illegible] 25		23 2
Nov 48	26 13	27 02	26 -27	19 -25	23 4	21 44	19 2	16 -17		23 47
Dec 4[illegible]	30 -26	2[illegible] -02	27 22	24 01	24 -12	22 33	7 59	24 50	13 4	21 -37
Jan 49	14 01	26 02	30 -1[illegible]	24 03	13 58	15 69	12 -91	12 71	16 110	25 -37
Feb 49	24 -46	24 -11	23 16	19 -27	16 6	16 10	12 -107	16 8	12 10	6 48
Mar 49	30 -37	31 -15	29 -18	29 02	20 14	21 22	16 -17	12 -75	23 76	26 1
April 49	27 -26	29 -40	27 -02	26 -15	21 24	20 13	14 0	16 -71	14 -7	22 46
May 49	31 5	30 -16	28 -31	31 -11	27 -8	21 39	19 -30	21 18	23 37	29 11
June 49	29 -25	29 -01	30 -36	29 -47	24 8	21 34	20 -84	11 -10	21 22	26 33
July 49	31 -06	31 00	31 -48	29 -15	29 -3	19 68	23 -65	11 -98	20 27	29 45
Aug 49	29 -04	31 -15	30 -36	29 -23	23 0	17 36	23 -109	17 -19	19 -4	29 46
Sept 49	28 -17	27 -26	27 -30	29 -06	24 10	17 43	18 -44	13 -4	19 34	24 -1
Oct 49	28 07	30 09	30 -05	30 -06	27 -41	16 -78	23 16	17 26	16 64	26 [illegible]

Table 1. (Continued)

	879	896	907	913	915	917	91[illegible]	924	934	945
	27	27	14		7	23		24		14
Sept 48	-27	-31	-5		32	2[illegible]		43		-22
	27	29	11		10	18	8	14	15	22
Oct 48	-10	-25	64		-19	29	-39	-29	41	-41
	30	28	19	18	21	24	22	24	19	26
Nov 48	-6	37	22	108	11	-10	10	-5	-16	21
	23	28	26	24	22	17	23	17	24	10
Dec 48	5	25	19	-3	19	-2	-9	-20	9	-20
	28	27	19	25	19	4	16	25	16	
Jan 49	19	-10	13	26	-47	59	4	2	-5	
	24	25	25	23	24		15	26	21	
Feb 49	11	-40	9	33	34		-16	2	-30	
	27	29	27	29	27	27	22	24	24	
Mar 49	21	-54	70	[illegible]	48	16	-13	-1	-1	
	21	20	22	27	24	21	13	23	15	11
April 49	26	-36	34	-11	59	6	73	7	-12	-107
	25	29	28	26	20	25	16	25	25	20
May 49	-26	-69	65	-23	33	-42	53	1	-6	-100
	29	2[illegible]	22	25	24	16	17	25	25	20
June 49	-17	-92	7	-15	43	14	7	-10	-32	-45
	31	29		23	24	27	20	28	27	31
July 49	-29	-59		-6	30	-7	34	-5	-4	-36
	25	22	9	21	12	12	9	27	30	14
Aug 49	23	-41	-23	-9	62	-59	-15	10	2	0
	25	30	19	20		23	9	25	2[illegible]	
Sept 49	-16	-1[illegible]	55	30		-12	63	-2[illegible]	37	
	25	22	20		15	26	4	27	29	21
Oct 49	-12	-25	14		-53	44	-43	-16	-5	-16

[illegible]

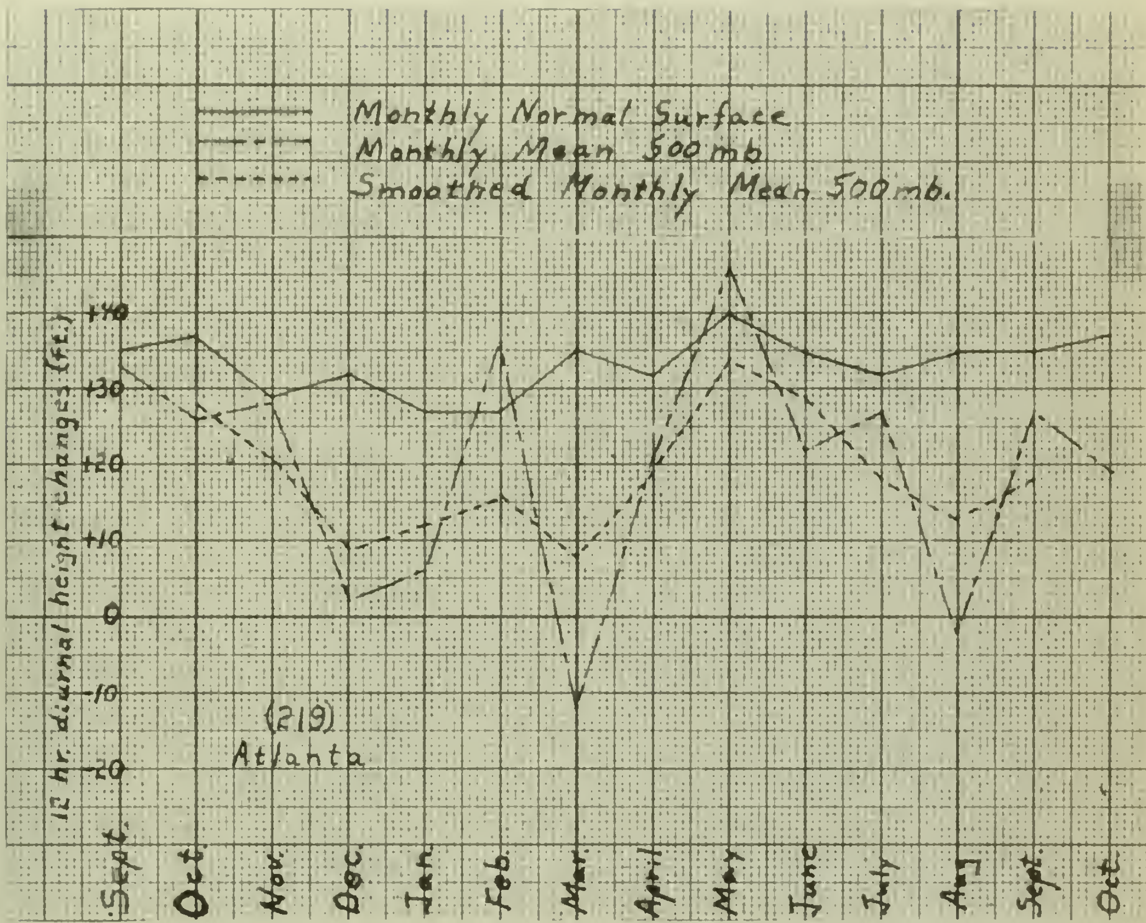
Table 1. (Concluded)

	964	958	043	074	050	105	016	040 or 101	94- or 102
Sept 48	27 -32		26 -24		3 -140	17 -45		16 1	
Oct 48	1[illegible] -16	12 -27	28 -26		6 -102	24 -66		24 -1	
Nov 48	2[illegible] -17	27 -3	24 -15		1[illegible] -54	22 -43		21 -17	
Dec 48	2[illegible] 5	19 -18	15 -55		19 -22	19 -63		19 -45	
Jan 49	27 -60	25 1	24 -60	7 12	14 -19	24 -16	15 21	17 -5	
Feb 49	23 -22	15 -37	21 -12	15 5	20 -26	23 -2[illegible]	16 3	15 1[illegible]	
Mar 49	27 -54	12 -17	27 -30	23 -19	15 6	2[illegible] -16	5 57	21 1[illegible]	10 -6
April 49	29 -29	25 -63	2[illegible] 21	20 -24	14 -44	23 -9		17 2	21 1
May 49	26 -54	12 -82	28 -2	24 6	20 -1	25 -12	13 -23	19 8	19 -65
June 49	30 -37	19 -66	28 -15	21 -15	20 31	25 -15	3 88	27 17	26 -52
July 49	26 -36	29 -74	29 -39	28 -31	21 -45	26 -62	11 169	26 -27	25 -23
Aug 49	21 -20		27 -41	18 -15	9 13	19 -130		26 -21	25 -34
Sept 49	28 -35		29 1[illegible]	25 26	4 6[illegible]			24 -6	26 -23
Oct 49	24 67		23 14	23 -13	17 49		7 126	23 -10	16 -45

Month	Station	Mean (ft)	Standard deviation (ft)	Extremes min/ max	Range (ft)	95% Confidence limits	Confidence level for 5 ft.	(yrs)
Sept 1948	445	17	47	-90/100	190	2<m<32	71%	9
Oct 1948	536	44	116	-170/340	510	8<m<80	59%	45
Nov 1948	365	14	100	-230/160	390	-17<m<45	60%	36
Dec 1948	712	15	133	-285/275	560	-26<m<56	55%	64
Dec 1948	451	24	124	-410/220	630	-14<m<62	53%	56
Jan 1949	712	40	178	-310/360	670	-15<m<95	56%	114
Feb 1949	219	37	90	-250/305	555	8<m<66	61%	30
Mar 1949	211	38	46	-35/160	195	24<m<62	72%	[illegible]
Mar 1949	747	26	106	-290/150	440	-58<m<6	60%	41
May 1949	553	13	93	-270/200	470	-16<m<42	61%	31
May 1949	265	17	37	-45/105	150	6<m<28	77%	5
June 1949	394	-16	47	-100/55	155	-31<m<-1	71%	[illegible]
June 1949	405	2	58	-140/160	300	-16<m<20	67%	13
July 1949	775	0	83	-190/180	370	-26<m<26	62%	25
July 1949	340	34	43	-70/150	220	30<m<56	73%	7
Aug 1949	597	-14	58	-180/55	235	-32<m<4	67%	13
Sept 1949	426	-9	46	-100/95	195	-23<m<5	71%	[illegible]
June 1949	219	22	33	-30/105	135	12<m<32	79%	4
Mar 1949	219	-12	97	-345/145	490	-43<m<19	60%	34
Dec 1948	219	2	125	-430/150	580	-37<m<41	53%	57
Sept 1948	219	33	43	-60/105	165	19<m<47	73%	7
Sept 1949	219	27	69	-90/330	420	5<m<49	65%	19
Sept 1948 & Sept 1949	219	30	57	-90/330	420	18<m<42	74%	12

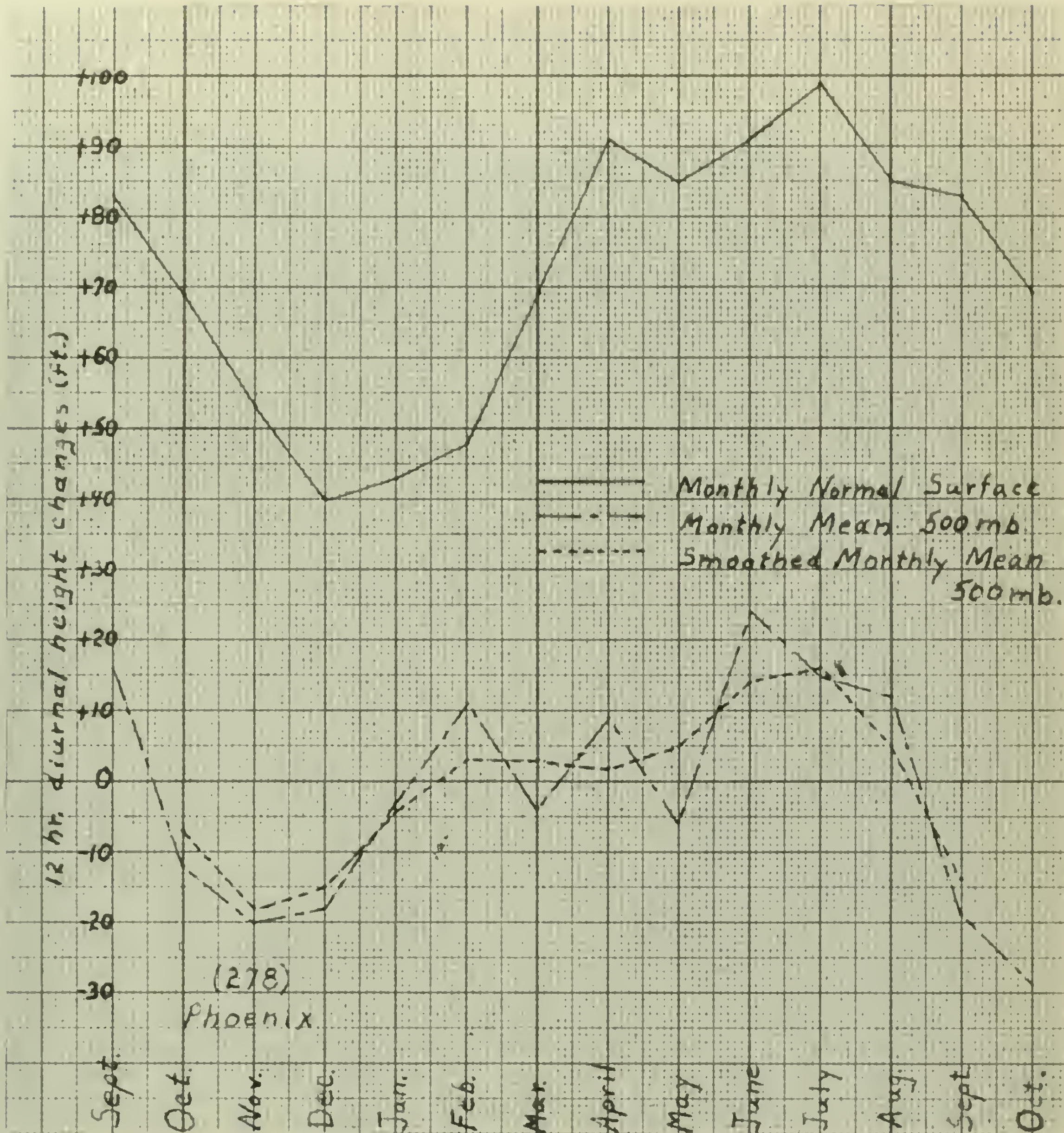
Table of statistical analyses of results for selected stations

Table 2.



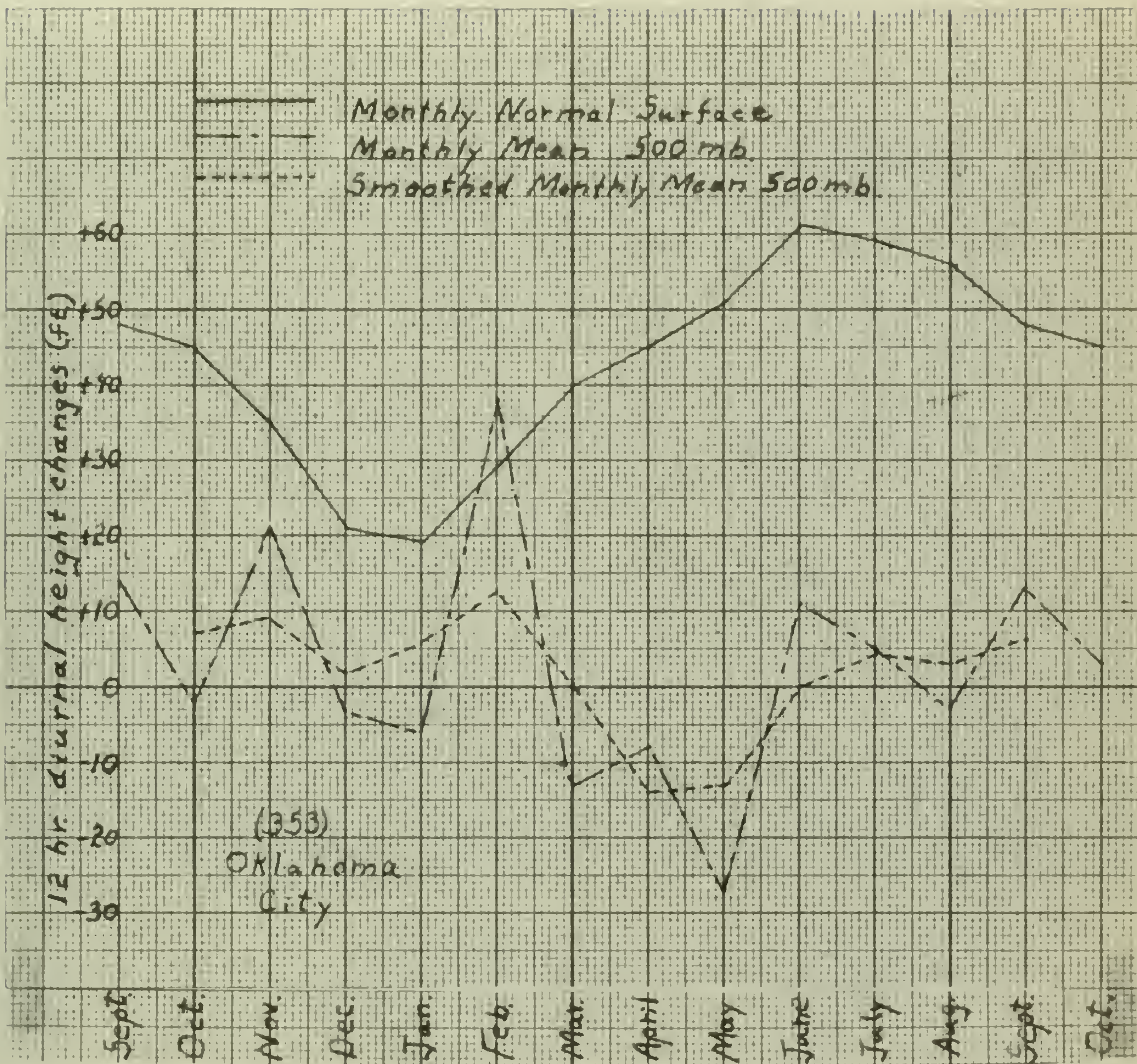
A comparison of the annual variations of the surface and 500 mb diurnal height changes for Atlanta.

Figure 1.



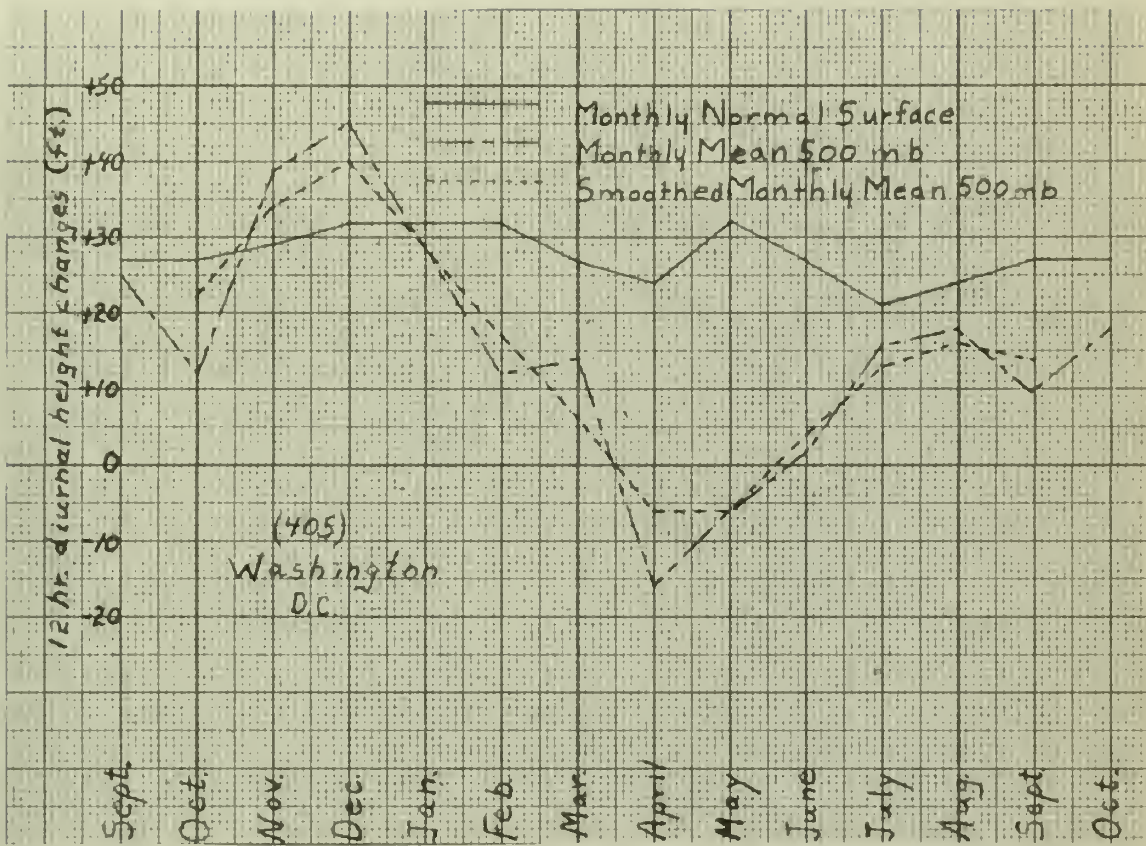
A comparison of the annual variations of the surface and 500 mb diurnal height changes for Phoenix

Figure 2.



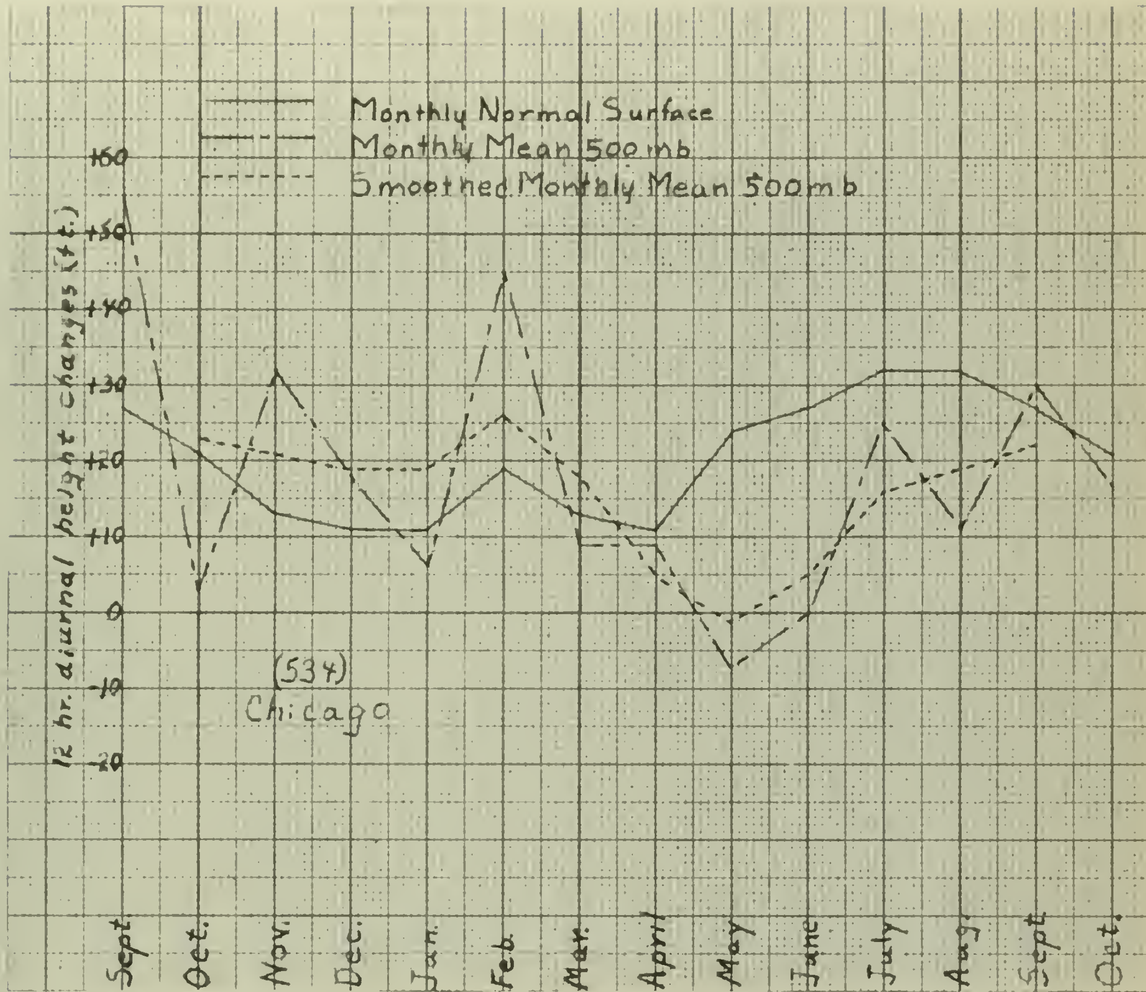
A comparison of the annual variations
of the surface and 500 mb diurnal height
changes for Oklahoma City

Figure 3.



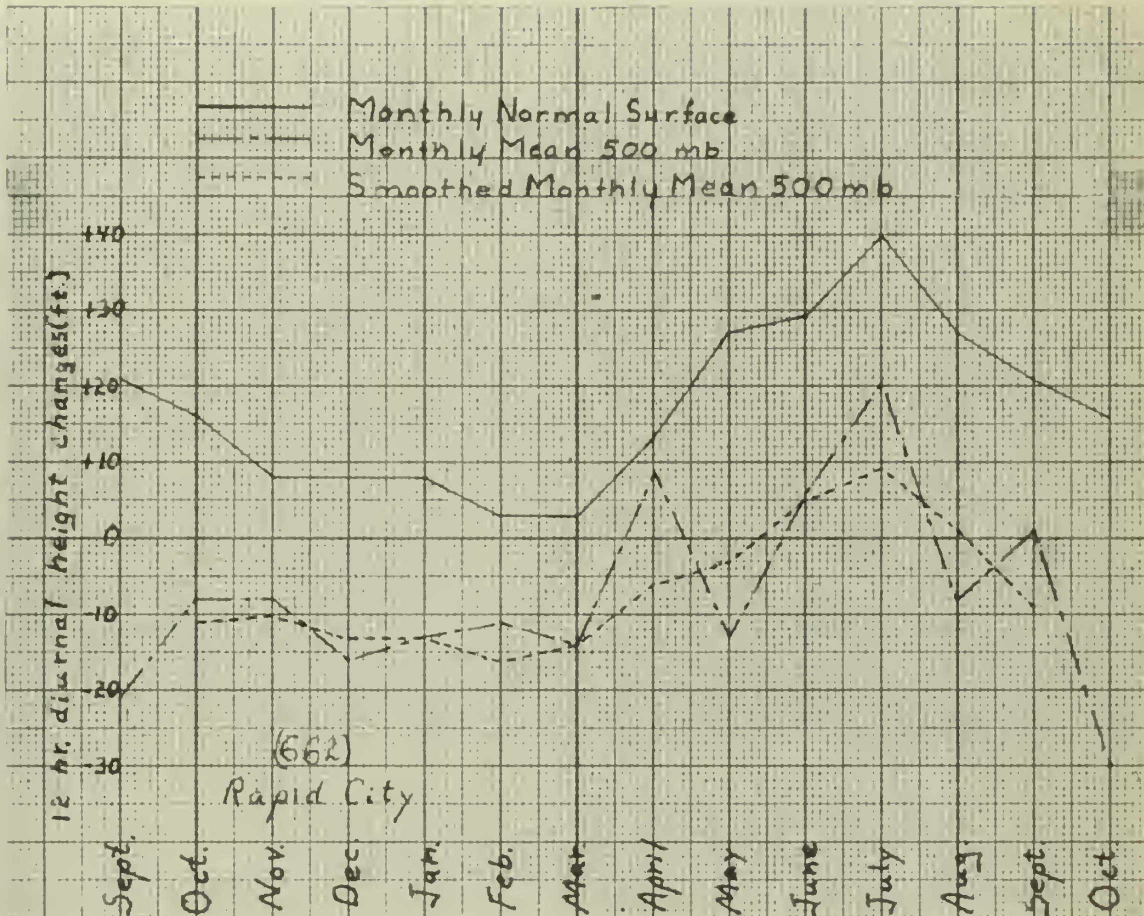
A comparison of the annual variations of the surface and 500 mb diurnal height changes for Washington, D. C.

Figure 4.



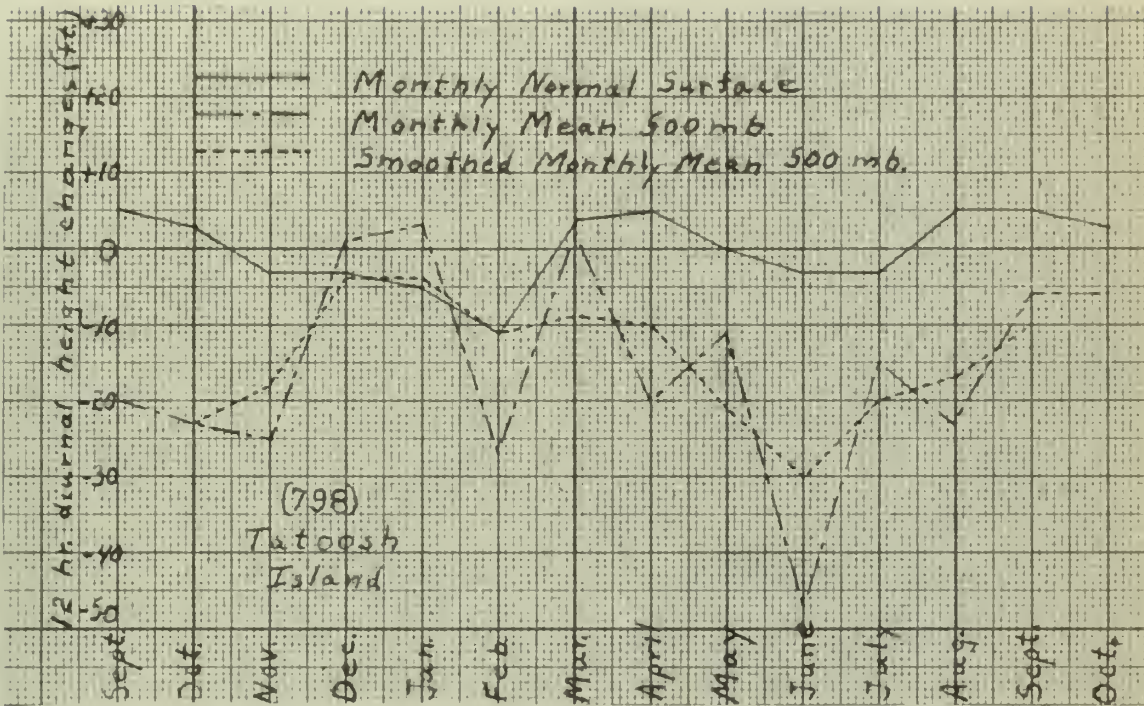
A comparison of the annual variations
of the surface and 500 mb diurnal height
changes for Chicago

Figure 5.



A comparison of the annual variations of the surface and 500 mb diurnal height changes for Rapid City

Figure 6.



A comparison of the annual variations
of the surface and 500 mb diurnal height
changes for Tatoosh Island

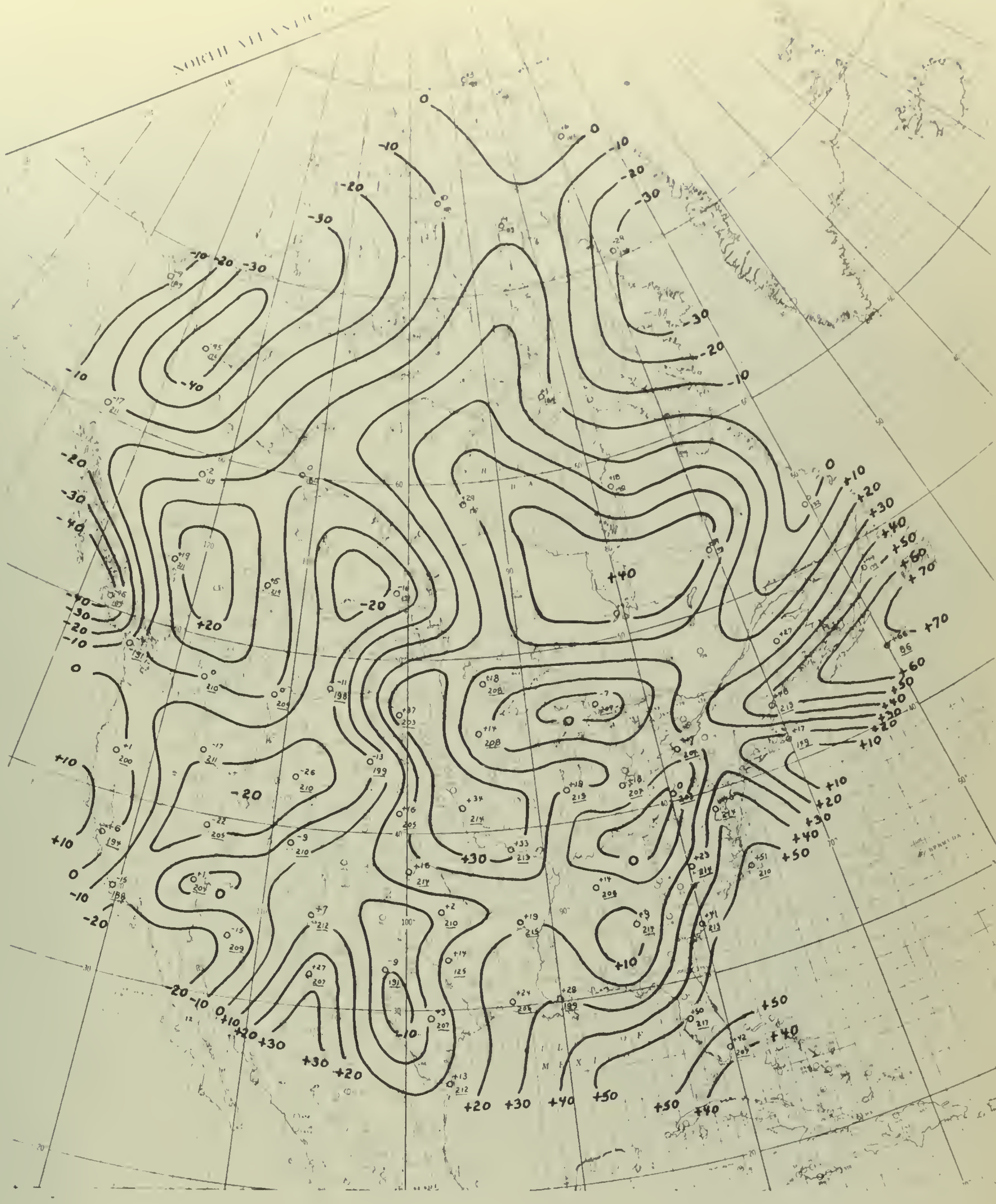
Figure 7.

The 500 mb mean diurnal height changes for October, 1948

Figure 8.

The 500 mb mean diurnal height
changes for November, 1948

Figure 9.



The 500 mb mean diurnal height changes for December, 1948

Figure 10.

The 500 mb mean diurnal height
changes for January, 1949

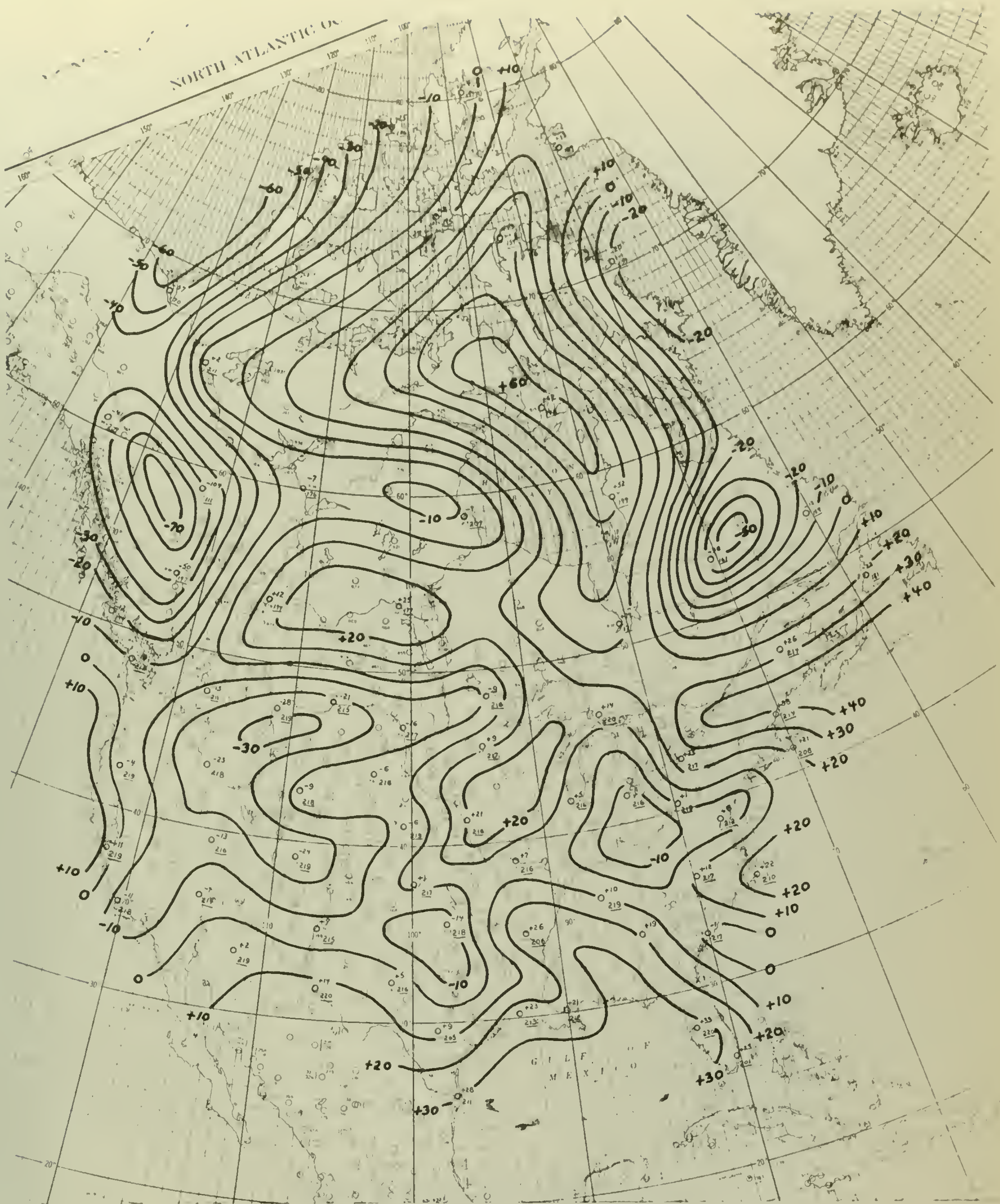
Figure 11.

The 500 mb mean diurnal height
changes for February, 1949

Figure 12.

The 500 mb mean diurnal height
changes for March, 1949

Figure 13.

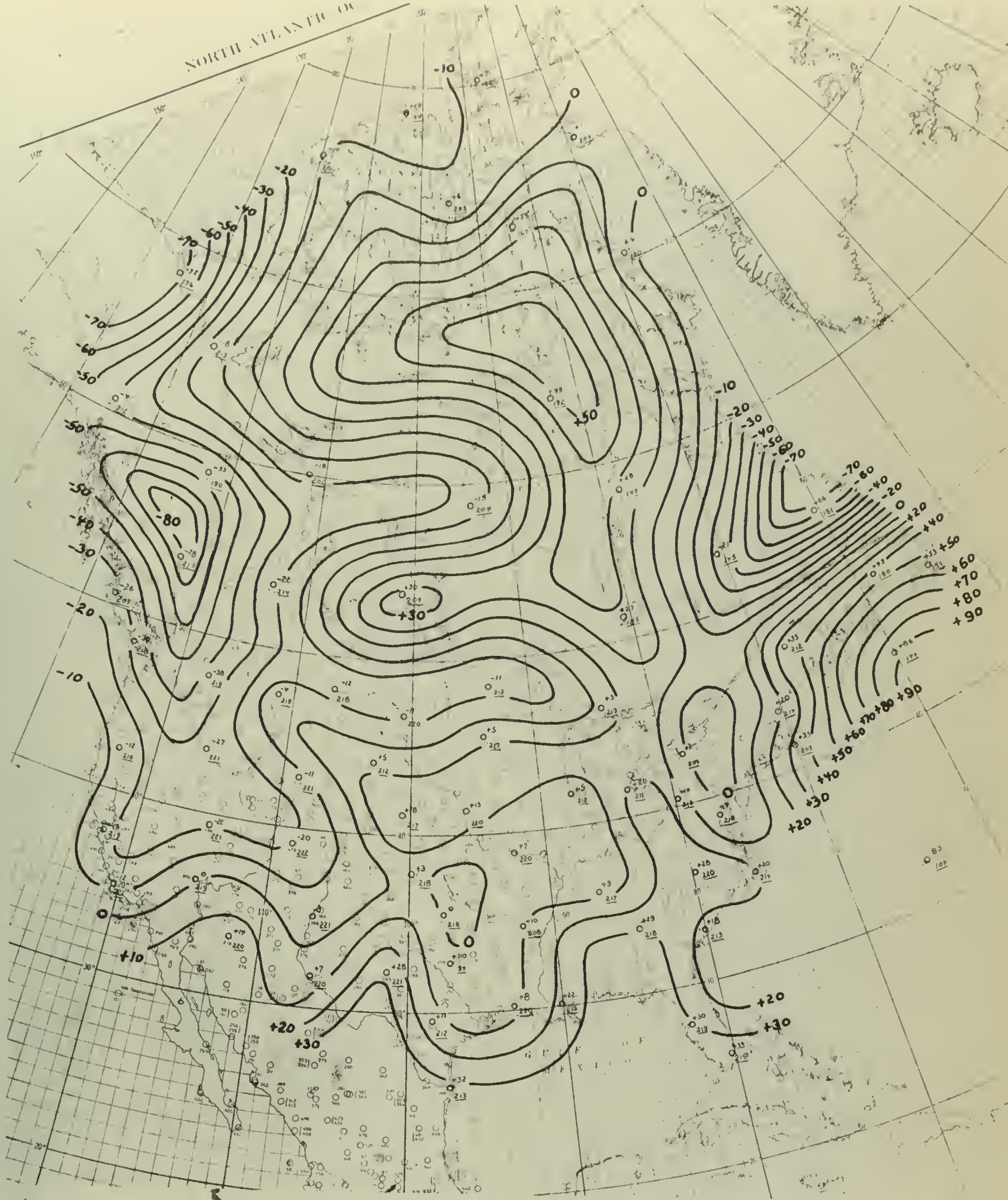


The 500 mb mean diurnal height
changes for April, 1949

Figure 14.

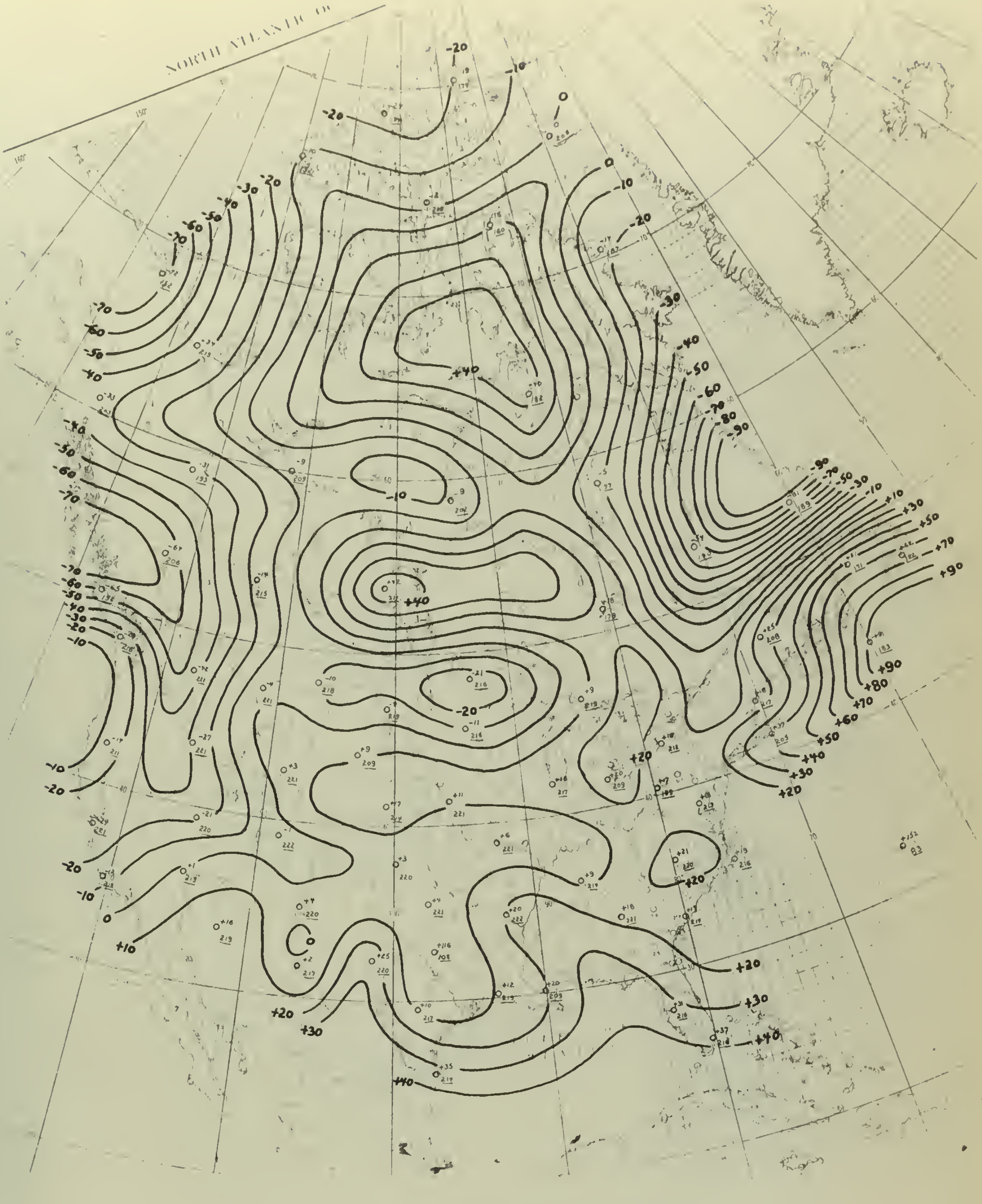
The 500 mb mean diurnal height
changes for May, 1949

Figure 15.



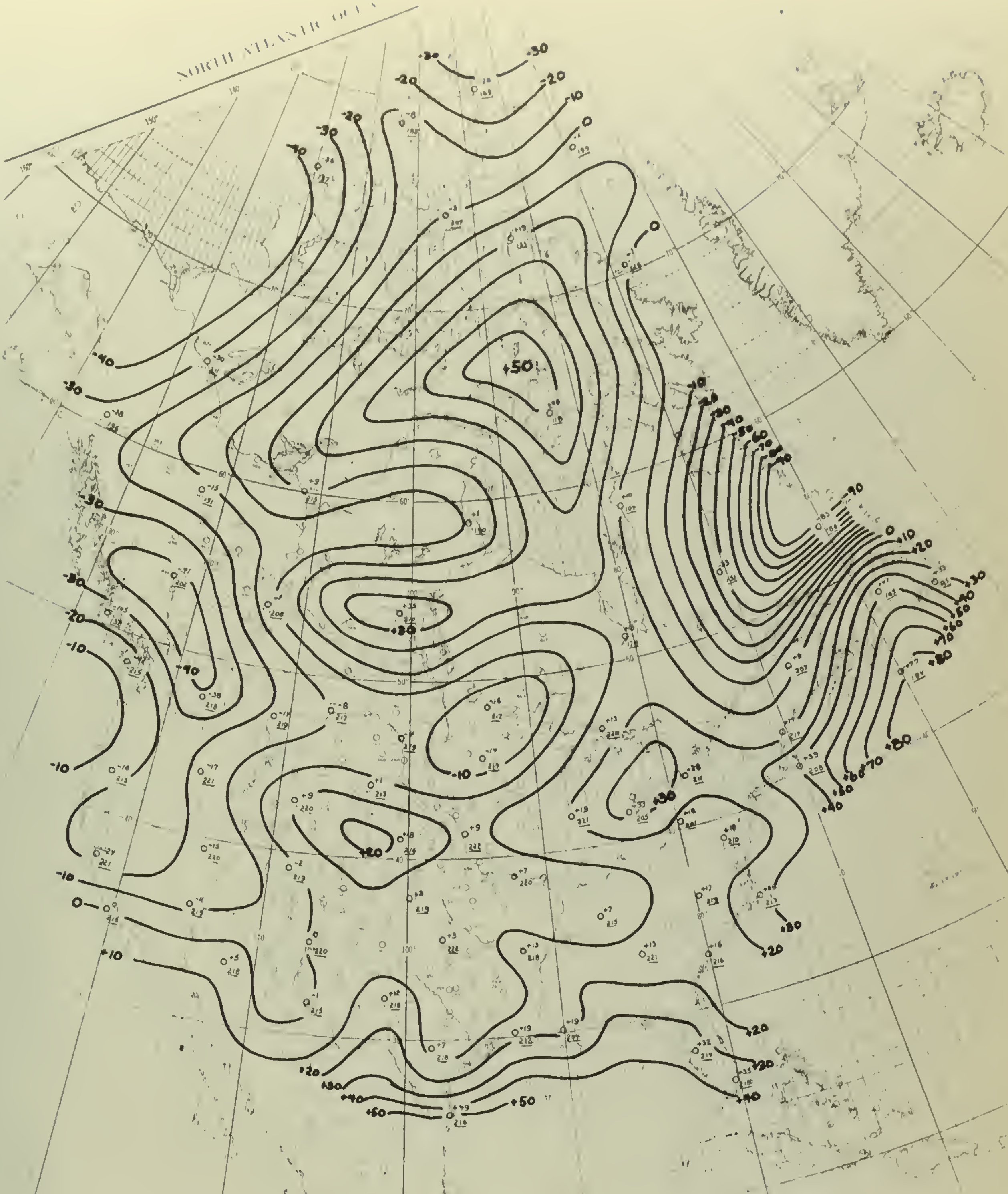
The 500 mb mean diurnal height
changes for June, 1949

Figure 16.



The 500 mb mean diurnal height
changes for July, 1949

Figure 17.

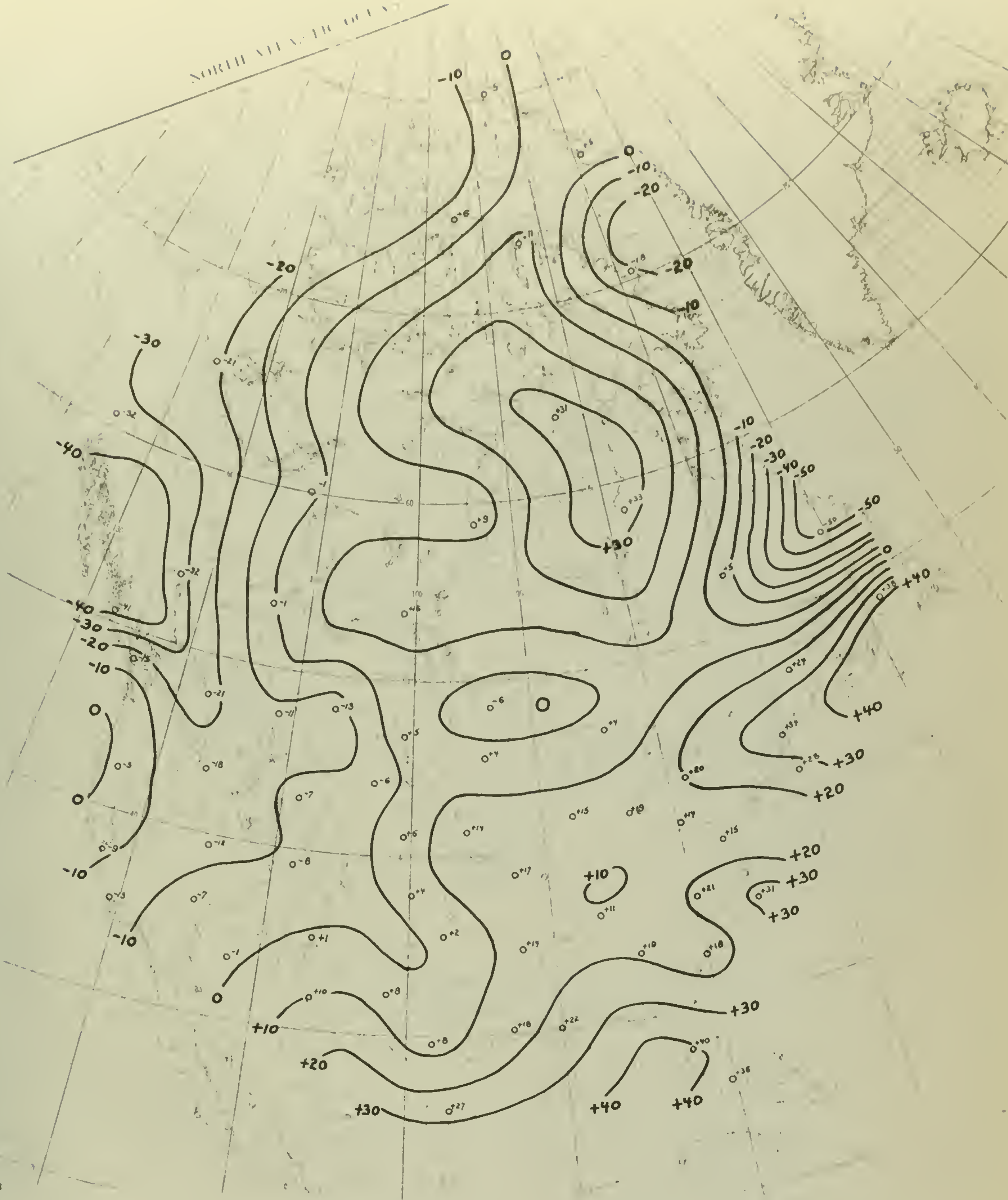


The 500 mb mean diurnal height changes for August, 1949

Figure 18.

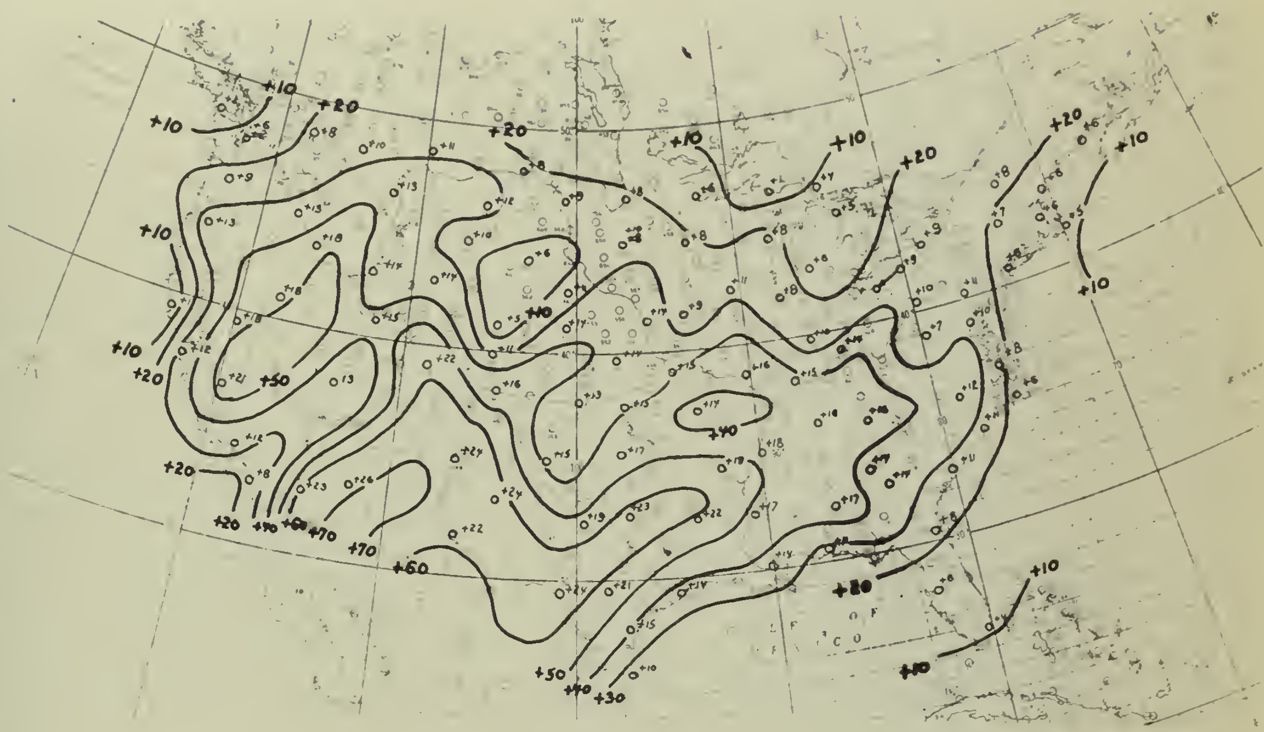
The 500 mb mean dirunal height
changes for September, 1949

Figure 19.



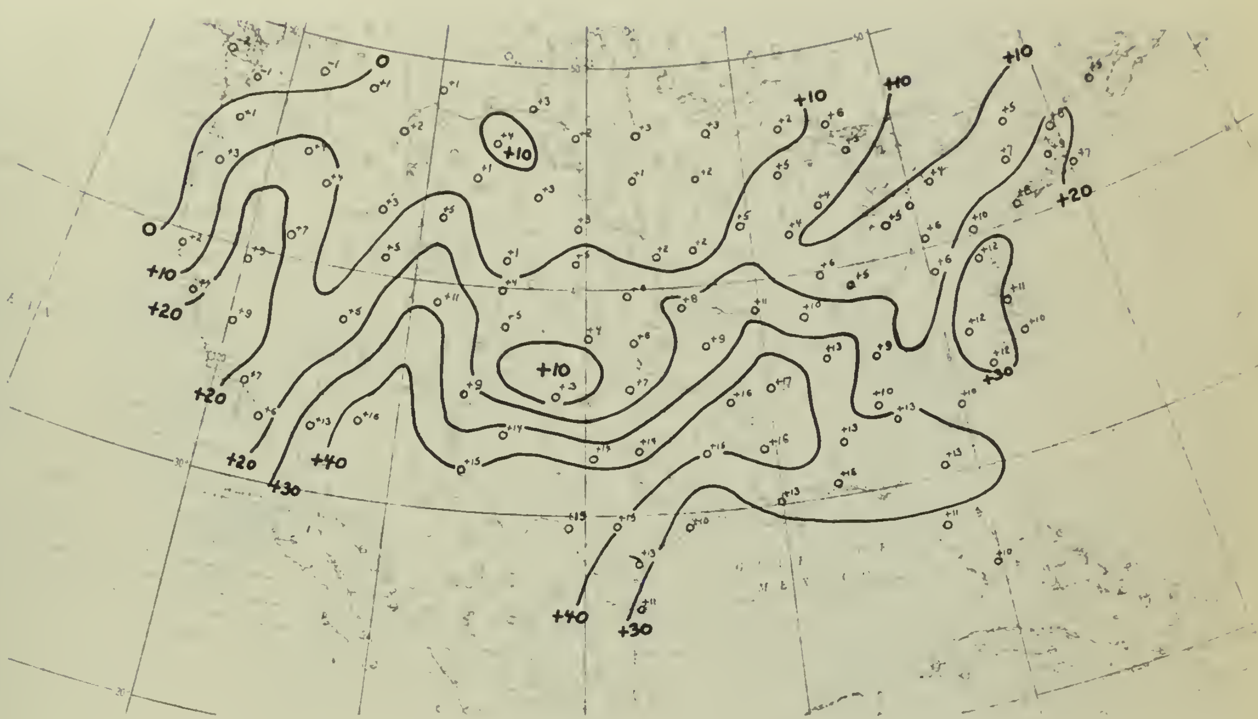
The 500 mb annual mean diurnal changes based on the period October, 1948, to September, 1949, inclusive

Figure 20.



The normal surface diurnal height
changes for October

Figure 21.

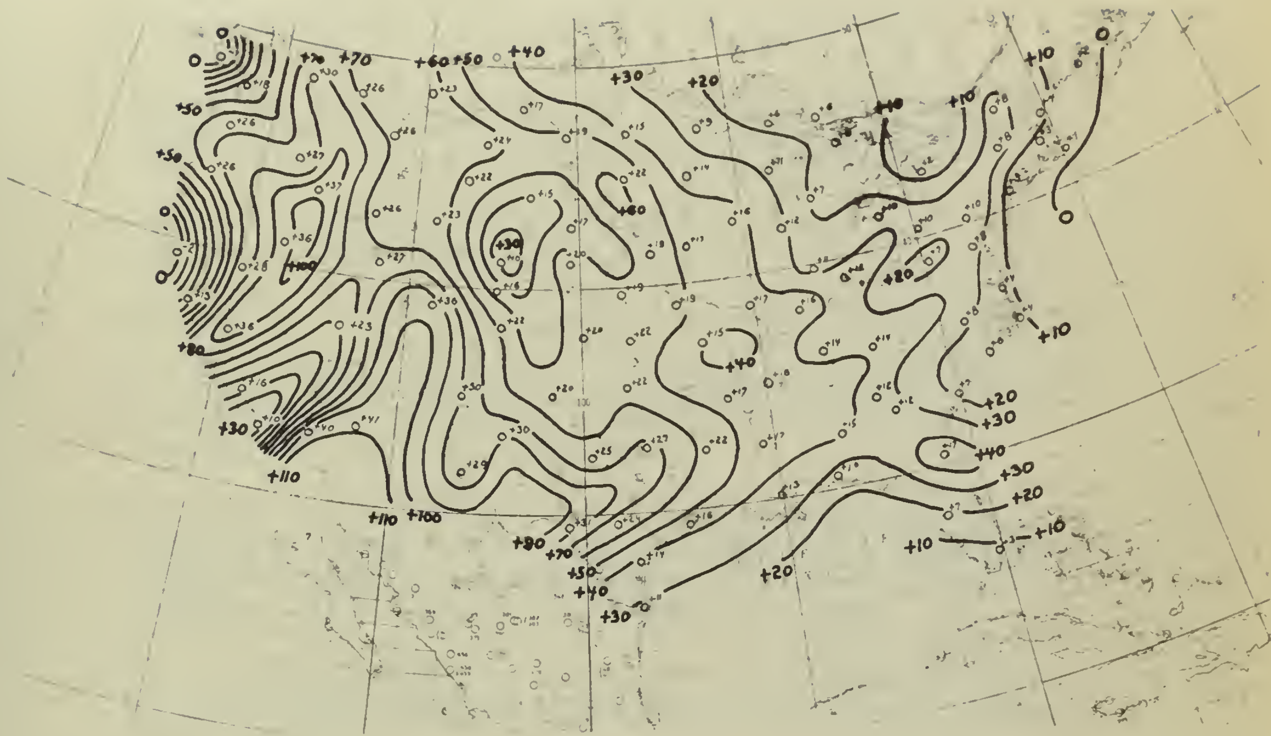


The normal surface diurnal height
changes for January

Figure 22.

The normal surface diurnal height changes for April

Figure 23.



The normal surface diurnal height
changes for July

Figure 24.

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